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INNOVATIVE DECENTRALIZED DECISION-MAKING ENABLING CAPABILITY ON MOBILE EDGE DEVICES

by

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September 2015

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13. ABSTRACT (maximum 200 words)

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The purpose of this study was to analyze the requirements and feasibility of adapting a local cloudlet model for enabling mobile application deployment and data dissemination capability to Marine units in an expeditionary environment. An empirical analysis comparing current systems requirements to the cloud model system requirements was performed. Additionally, an evaluation was conducted on the impact of mature technologies from academia, government, and commercial research onto availability of local cloudlet at the tactical edge. The significance of the aforementioned analysis and evaluation determined the local cloudlet model provided an operationally viable alternative to the current method of information sharing in edge organizations. This study should prompt the Marine Corps to invest in further research.

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INNOVATIVE DECENTRALIZED DECISION-MAKING ENABLING CAPABILITY ON MOBILE EDGE DEVICES

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LIST OF ACRONYMS AND ABBREVIATIONS

2D/3D	two dimensional/three dimensional
AES	advanced encryption standard
AFATDS	advanced field artillery tactical data system
A2AD	anti-access/area denial
API	application programming interface
AOR	area of responsibility
BN	battalion
BFSA	battlefield situation awareness
BLOS	beyond line of sight
CAPSET	capability set
CIO	chief information officer
CWM	cognitive world model
CD&I	combat development and integration
CS	combat support
CSS	combat service support
C2	command and control
C4	command, control, communications, and computers
C4ISR	command, control, communications, computers, intelligence surveillance and reconnaissance
CCIR	commander's critical information requirements
COC	command operation center
COBRA3	command operation center battlefield remote access and awareness applications
CP	command post
COTS	commercial-off-the-shelf
COMSATOM	commercial satellite communication
COP	common operational picture
CTP	common tactical picture
COE	concept of employment
CBA	cost/benefit analysis

COIN	counterinsurgency
DVCOTM	data and video communications-on-the-move
DaaS	Data-as-a-Service
D2D	data-to-decision
DDS-M	data distribution system modular
DISN	Defense Information Systems Network
DOD	Department of Defense
DODIN	Department of Defense Information Network
DEOS	deployable end office suite
D-DIL	denied disconnected, intermittent, and limited
DWM	digital world model
DIL	disconnected, intermittent, and limited
FoS	family of systems
FSS	fixed satellite services
FOB	forward operating base
FOA	freedom of action
FOM	freedom of movement
GIG	global information grid
GPS	global position system
GOTS	government-off-the-shelf
GUI	graphical user interface
HMMWV	high mobility multipurpose wheeled vehicle
HHQ	higher headquarters
IAW	in accordance with
ICB	infantry company and below
IER	information exchange requirements
IT	information technology
IaaS	Infrastructure-as-a-Service
IISR	integrated intra-squad radio
IFC	intelligence fusion center
IPB	intelligence preparation of the battlespace
ISR	intelligence, surveillance, and reconnaissance

JLTV	joint light tactical vehicle
LOS	line of sight
LAN	local area network
LEM	LAN extension module
MAGTF	Marine Air Ground Task Force
MCCDC	Marine Corps Combat Development Command
MCDP	Marine Corps Doctrinal Publication
MCWP	Marine Corps Warfighting Publication
MDM	master data management
MEDEVAC	medical evacuation
METOC	meteorological and oceanographic
MILSATCOM	military satellite communication
M2C2	mobile modular command and control
MRC	mobile radio communications
MSS	mobile satellite services
MDX	multidimensional extensions
NIST	National Institute of Standards and Technology
NOTM	network on-the-move
NextGen	next generation
NGO	non-governmental organization
NIPRNet	non-secure Internet protocol router network
OLAP	on-line analytical processing
OLTP	on-line transactional processing
OTH	on-the-halt
OTM	on-the-move
OTP	on-the-pause
OFTCS	one force tactical communication system
OEF	OPERATION Enduring Freedom
OTH	over-the-horizon
OIF	OPERATION Iraqi Freedom
OpSec	operational security
OGA	other government agencies

PWM	physical world model
PaaS	Platform-as-a-Service
POP	point-of-presence
PRC	portable radio communications
PLI	position location information
PoR	program of record
RAM	random access memory
ROMO	range of military operations
R&D	research and development
RSAM	remote subscriber access module
SATCOM	satellite communications
SIP	secret Internet protocol
SIPRNet	secure Internet protocol router network
SAASM	selective availability anti-spoofing module
SBUIP	sensitive but unclassified Internet protocol
SINCGARS	single channel ground and airborne radio system
SA	situation awareness
SaaS	Software-as-a-Service
SOP	shared operational picture
SoS	system of systems
TO/E	table of organization and equipment
TSM	transition switch module
TIC	troops-in-contact
UNS	universal needs statement
VMF	variable message format
VRC	vehicular radio communications
VSAT	very small aperture terminal
VoIP	voice over Internet protocol
VoSIP	voice over secure Internet protocol
V2D	voice, video, and data
WSM	wavelength services manager
WPPL	wireless point-to-point link

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I. INTRODUCTION

While deployed to Afghanistan, the researchers experienced firsthand the challenges associated with planning, installing, operating, and maintaining an enterprise tactical network. As Communications Officers, the researchers were responsible to the commander for ensuring a flexible, interoperable, secure, reliable, survivable, and timely network capable of supporting the critical command and control (C2) assets needed for effective decision-making. The challenge posed to the researchers was to satisfy commanders at all levels' information requirements in a resource-constrained environment. At the higher headquarters (HHQ), commanders and their staffs were outfitted with multiple high throughput satellite communication terminals and their command post became the communication integration hub for all subordinate units. The robust network infrastructure located there provided a digital communication backbone that was capable of supporting all Defense Information Systems Network (DISN) (voice, video, and data [V2D]) capabilities.

When visiting HHQ, the researchers noticed a command operation center (COC) that was effectively processing the information critical to maintaining combat operation superiority (U.S. Marine Corps, 2010a, p. 1-1). At this location, bandwidth limitations, throughput capacity, and resource constriction were not a factor. How was it that a location farthest removed from the tactical edge was equipped with primary, secondary, and tertiary communication assets? The imbalance of resources in favor of the HHQ contradicted some of the tenets echoed in Marine Corps Warfighting Publication (MCWP) 3–40.3.

> The MCS must be able to satisfy the C2 requirements of the expeditionary battlefield. It must provide Marine Air Ground Task Force (MAGTF) commanders and their staffs with the tools necessary to collect, process, analyze, and exchange information rapidly in support of operations planning and execution. These systems must make the necessary information available when and where it is needed on the battlefield. Employment of these systems must not adversely affect the MAGTF's freedom of action (FOA) and mobility, and they must be reliable, flexible, responsive, and configurable to mission needs. The success of the MAGTF on the modern battlefield depends on designing, planning, and

> employing a communications system that satisfies the information needs of the MAGTF process. (U.S. Marine Corps, 2010a, p. 1-2)

The researchers' dilemma centered on maximizing capability without sacrificing flexibility. This calls to attention a perceived technology gap between the information required to support the decision makers and the capabilities/limitations of the equipment provided to the lower echelons of command. Unlike the researchers' command post (CP), which actively relocated throughout the dynamic and fluid area of responsibility (AOR), these fortified communication hubs were positioned on permanent bases that had received commercial upgrades. These enhancements provided HHQ commanders and their staffs with the same C2 capabilities they had trained on during command post exercises prior to deployment.

"Train like you fight" is an adage commonly used throughout the Marine Corps. At its basic level, it describes the need to simulate combat as realistically as possible and to maximize the battlefield advantages gained from leveraging technically superior equipment. The Marine Corps in conjunction with private and government institutions has developed and adopted various systems and applications (COBRA3, AFATDS, M2C2) to assist commanders in improving the decision-making and information dissemination cycle. Dillingham and Nathans (2007) stated that a critical factor in accomplishing net-centric warfare and operations is to provide the warfighter at the tactical edge with vital information at critical points in battle through access to the Global Information Grid (GIG).

In garrison, commanders have the benefit of an established commercial network architecture that connects the otherwise bandwidth/throughput intensive applications and systems they use to model crises and contingencies. Battle simulation centers place commanders in ideal environmental conditions, and are equipped with the latest and greatest of innovations designed for the Marine Corps. Commanders are able to participate in exercises using hardwired equipment that connects the higher echelon (major subordinate command) to the lower echelon (platoon). This construct enables all participants to effectively war game scenarios and resolve any procedural issues without having to deploy to the field. As realistic as it is supposed to be, it does not account for network latency or the unavailability of an asset—in other words; it is a perfect scenario.

In combat, commanders are exposed to the harsh reality of the lack of, or limitations of their organic "command, control, communications, computer, intelligence, surveillance, and reconnaissance (C4ISR) equipment" (National Academics Press, 2006, p. 1). Without being directly connected to their subordinates via Ethernet, commanders are now forced to rely on communicating using tactical assets. HHQ commanders insist on receiving what has been deemed critical information to accurately assess the developing situation and issue orders, in spite of the subordinate commander at the tactical edge not having the assets required to process the request for information. This capability gap has resulted in the need to provide small unit leaders with an improved range of capabilities in the following areas: blue and red force position reporting; receive real-time video from all available platforms; close air support request; and increased situation awareness through collaboration and C2 (Young & Ishii, 2012, pp. 1–4).

The Cebrowski Institute recognized this shortfall and concluded the research in this area is driven by a deficiency in communication dissemination capabilities observed by tactical units, while participating in humanitarian assistance and disaster relief (HADR) efforts, or during full-scale kinetic operations (Military Wireless Communication, n.d.). The researchers observed the challenges mobile forces faced when issued a mission, outfitted with specific C2 equipment, and tasked to perform distributed operations in an austere environment (Military Wireless Communication, n.d.). The program of record (PoR) equipment assigned, in accordance with a unit's table of organization and equipment (TO/E) allowance, challenged the ability for the subordinate units to conduct maneuver warfare throughout their assigned AOR; while simultaneously maintaining uninterrupted communications links with their HHQ COC. The current Department of Defense (DOD) communications equipment used in support of combat operations require fixed or stationary transmission systems. The ability to rapidly gather, process, and disseminate information to decision-makers while maintaining FOA and freedom of movement (FOM) is essential at the tactical edge.

This research is to study the feasibility of developing this capability and the overall added value to the United States Marine Corps by procuring such a capability. The researchers propose that maintaining a highly mobile, rapidly deployable, tactical force capable of conducting decentralized distributed operations at the tactical edge does not have to come at the sacrifice of mission-essential V2D capabilities. Adapting a Platform-as-a-Service (PaaS) model to meet the needs of an expeditionary force may allow the USMC to reduce the time in the data-to-decision (D2D) cycle at the tactical edge.

A. PROBLEM STATEMENT

In 2011, the National Military Strategy directed the improvement in the ability to rapidly respond to crisis with little to no warning; deploy and employ flexible C2 assets, and become a more scalable force (Chairman of the Joint Chiefs of Staff, 2011). Admiral Mullen envisioned a Joint Force with the capability to collect information, conduct analysis, and distribute intelligence products (Chairman of the Joint Chiefs of Staff, 2011). Since inception, the Marine Corps has been that expeditionary force capable of conducting multifaceted operations. Former Commandant General Krulak (1999) referred to this as the "three block war." Essentially, Marines must be trained to prosecute full-spectrum warfare (humanitarian assistance, peace-keeping operations, and full-scale military action) within a radius of three contiguous city block. Over the past decade, the Marine Corps has participated in a protracted multi-theater counterinsurgency (COIN) campaign. The United States' national interest abroad required the USMC to become an occupying force operating out of tactical forward operating bases (FOB) with commercialized communication infrastructure supporting the HHQ.

At the company down to the squad level, the organic communication assets were incompatible with the demand levied upon the commander to provide situational updates in real-time. Tactical forces are inundated with request for information that required the usage of multiple "single-frequency-spectrum-capable" devices in order to satisfy the insatiable appetite of their HHQ (Oregon, 2011, p. 3). This resulted in universal needs statement (UNS) from combatant commanders detailing a requirement for C4ISR procurement. The influx of new equipment provided the capability but also increased the logistical burden and further limited mobility since tactical forces were reinforced with multiple devices to perform the six war-fighting functions outlined in Marine Corps Doctrinal Publication (MCDP) 1–0, Marine Corps Operations: C2, Intelligence, Maneuver, Fires, Logistics, and Force Protection (U.S. Marine Corps, 2011a, p. B-1).

If a single mobile government-off-the-shelf (GOTS) communication device were configured to provide warfighting functionality (V2D, fires support, medical evacuation, instant messaging, friendly force location, and enemy force location) through hosting secure military designed applications, then this capability would provide forces operating at the tactical edge increased flexibility in response to global conflicts. Former Commandant General Conway (2008, p. 3) stated "though our Corps has recently proven itself in 'sustained operations ashore,' future operational environments will place a premium on agile expeditionary forces, able to act with unprecedented speed and versatility in austere conditions against a wide range of adversaries."

The draw down in Afghanistan marks an end of a land-based theater support era for the USMC and provides an opportunity for a refocus on its fundamental roots as a sea-based, organically supported expeditionary organization. The shift in operational outlook requires research for a system that enables first in forces with the critical operational capabilities needed in support of the next generation (NextGen) of tactical warfighter. The current Marine Corps' units, at the tactical edge, are unable to access decision making applications in a contested environment. The contested environment is about supporting reliable/resilient distributed C2 when the upper level is no longer available and lower levels absorb the workload. The focus of this research is on the denied, disconnected, intermittent, and limited (D-DIL) environment, which is a subset of a contested environment with an emphasis on network constraints. End users at the forward edge of the battlefield are operating in a dynamic environment. The requirement to remain agile, highly responsive, and flexible to change does not coincide with the time intensive requirement to setup bulky stationary satellite communications equipment. Even when the tactical commander is able to operate out of a fortified position, their communication equipment still does not have the same throughput capabilities allocated as their higher headquarters resulting in latency or the inability to access automated applications such as Fires Request and Personnel Status Reports. The Marine Corps' CIO is interested in leveraging commercial-off-the-shelf/government-off-the-shelf (COTS/GOTS) open source data computing and delivery systems in order to provide warfighters, at every level, with a common operational picture throughout all phases of conflict. This research will focus on shared operational picture (SOP) by conducting an analysis of the benefits of adapting a local cloudlet model to host warfighting applications accessible by tactical edge units using mobile devices in D-DIL environments to improve collaboration, situation awareness, and decision making.

B. PURPOSE

The purpose of this study is to analyze the requirements and feasibility of adapting a local cloudlet model for enabling application deployment and data dissemination capability to Marine units in an expeditionary environment through a mobile device. Young et al. (2012, pp. 1–4) stated that at the tactical edge there is a requirement for intelligence and operations fusion capability in order to improve battlefield situation awareness (BFSA), friendly force preservation, fires accuracy, lethality, and tactical advantage. The significance of this is to determine if the aforementioned model provides an operationally viable alternative to the current method of information sharing in edge organizations. Specifically, the researchers will evaluate the impact of mature technologies from academia, commercial and government research onto availability of a local cloudlet at the tactical edge.

C. RESEARCH QUESTIONS

This thesis will be guided by the following questions:

- Is the tactical cloudlet a viable solution for extending enterprise end-to-end architecture to the edge users?
- Can a local cloudlet at the tactical edge be deployed to be readily accessible by the mobile device?
- What future capability requirements, hardware/software technology innovations are necessary to operate a mobile device in a D-DIL environment?

- What is the impact of leveraging mature technologies to enhance the decision support system (DSS) using local cloudlets at the tactical edge?

D. OBJECTIVES

The research will comprise several objectives:

- Analyze current and future requirements for a cloud computing solution at the tactical edge
- Compare current communication solution to the cloud model
- Provide analysis requirements for equipment and training
- Offer prototype solutions for a mobile device strategy
- Describe means to improve SOP, situation awareness, and decision-making on a mobile device in a D-DIL environment

E. METHODOLOGY

This research will compare current systems requirements to the cloud model system requirements. The literature review will establish a baseline for comparison using current capabilities and C2 requirements of the Marine Corps Infantry Company. The literature review will examine existing technological capability gaps and the commercial solution designed to fulfill the requirement. The literature review will end with examining the feasibility of adapting mobile device infrastructure into a future tactical cloud ecosystem.

F. SCOPE

The scope of this research is focused on the benefits gained by the USMC when adapting a cloud model to host C2 developed applications available to the warfighter via mobile device technology in order to improve the D2D capability of units at the tactical edge. This thesis will neither provide a standard operating procedure detailing the deployment of a cloud model and the hosted applications accessible by mobile devices, nor attempt to define security parameters or policies needed to be in compliance with DOD directives, policies, or standards. Operational security (OpSec) risk to C2 and acceptable usage policies within the DOD are potential limitations to this research. The research, as basis for comparison against existing tactical communications, will look at existing implementations as opposed to emerging conceptual ideas. The comparison will be limited to current legacy systems and a current alternative solution. The USMC Infantry Company and associated TO/E will serve as the base unit for the research.

G. THESIS ORGANIZATION

USMC requirements analysis of existing equipment deficiencies will be conducted using an empirical method. The analysis will present the benefits of a cloud model designed to incorporate mobile device architecture. The first chapter provides an overview and general observations of a deployed environment, which led to the questions that guided and focused the research. The second chapter is a literature review that establishes the USMC information technology (IT) framework for the tactical edge including a mobile device strategy using PaaS. This chapter will present the current information dissemination trends and the movement toward commercial mobile device technology. The second chapter will also introduce existing DOD and USMC policy and guidance toward mobile device technology acquisition. In-depth investigation of trends, policy, and guidance will aid in determining the current and future tactical level C2 capability requirements. Tactical level units' capability degradation, when systems are deployed in the following conditions: fixed—on-the-move (OTM)—dismounted, require an analysis of a future alternative. The third chapter will examine a hybrid cloud architecture, which includes operational cloudlet nodes linked to tactical cloudlet nodes. Within the tactical level cloudlet sub-architecture are user nodes operating in a D-DIL environment that requires connectivity to enterprise nodes in the presence of anti-access/area denial (A2AD) threats through mobile devices. In addition, this chapter will compare this architecture to current equipment at the tactical level. The fourth chapter will outline suggested mobile device prototype requirements and design. The fifth chapter will analyze Data-as-a-Service (DaaS) and the decision support system for mobile devices operating in the D-DIL environment in order to accelerate the decision-making ability. The sixth chapter provides conclusions and recommendations for future work.

II. LITERATURE REVIEW

The primary assignment of the Marine Corps Infantry Rifle Company is to "defeat the enemy by fire, maneuver, and close combat and to conduct other operations as directed across the range of military operations [ROMO]" (U.S. Marine Corps, 2014a, p. 1-3). Specifically, the infantry rifle company is tasked to "plan, coordinate, and conduct ground combat operations and type operations, as directed, across the spectrum of war in an expeditionary environment" (U.S. Marine Corps, 2014c, pp. 2–3). It achieves this by effectively employing personnel and equipment in order to maximize organic firepower as depicted in Figure 1 (U.S. Marine Corps, 1998, p. 4-7).

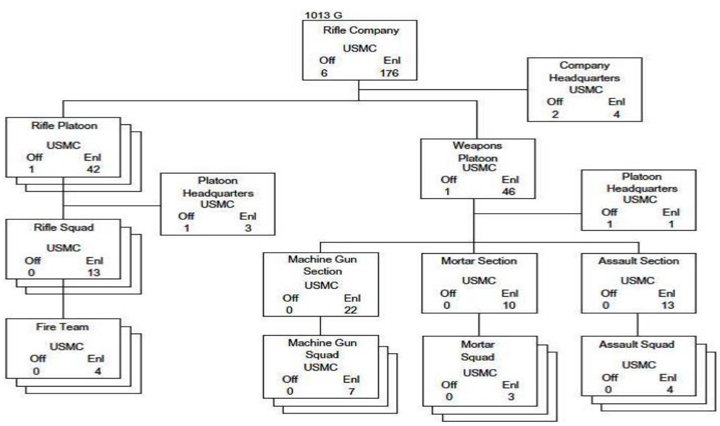


Figure 1. USMC Infantry Rifle Company
(from U.S. Marine Corps, 1998, p. 4-7)

A. ORGANIZATIONAL PERSONNEL AND EQUIPMENT

The personnel and equipment assigned to an infantry rifle company are in accordance with (IAW) a unit's TO/E, respectively. An infantry rifle company has six officers and 176 enlisted Marines (see Appendix A). It is outfitted with 176 PRC-153 integrated intra-squad radios (IISR) that act as wireless intercom system. The current T/E in Appendix B lists the 13 satellite communication capable radio systems: AN/VRC-110 quantity 2; AN/VRC-114 quantity 1; AN/PRC-117G(V)2 quantity 4; and AN/PRC-117F(V)1C quantity 6 (U.S. Marine Corps, 2014c, pp. 18-20).

B. EXPANDING INFORMATION DISTRIBUTION REQUIREMENTS, STRATEGY, AND CAPABILITY GAPS

At the onset of both OEF and OPERATION Iraqi Freedom, U.S. forces required the ability to communicate across all command levels in support of land, sea, and air operations. Beyond line of sight (BLOS) satellite communication (SATCOM)-capable portable terminals were essential for remote mobile unit communication. Military satellite communication (MILSATCOM) capacity alone was insufficient in meeting the information dissemination requirements and was augmented by commercial satellite communication (COMSATCOM) assets.

1. Satellite Communication Growth Trends

Due to end-user requirements, DOD procured COMSATCOM services as needed to augment MILSATCOM. COMSATCOM evolved from a complementary capability to a critical element of the DOD SATCOM architecture (U.S. Strategic Command, 2013). According to the Defense Business Board (2013), DOD views SATCOM as mission essential in providing the warfighter the communication resources needed in current areas of operations and new missions in new geographies. As shown in Figure 2, the DOD has significantly increased MILSATCOM's capacity in an effort to satisfy growing information demands placed on dispersed units conducting distributed operations.

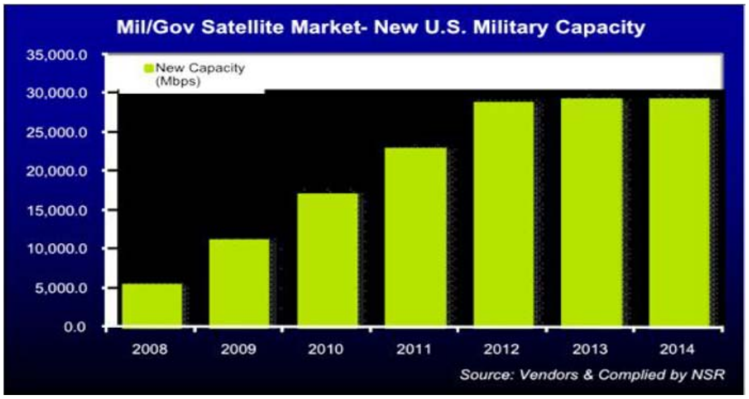


Figure 2. Military Satellite Capacity (from Defense Business Board, 2013)

As stated in Taking Advantage of Opportunities for Commercial Satellite Communications Services (2013), SATCOM meets the following warfighter requirements: interoperability; global coverage; assured, real-time access; capacity; protection; and flexibility. As COMSATCOM capabilities continue to expand, DOD's maximization of industry innovation and continued integration promote Joint Force 2020 Capstone Concept of highly-networked forces connected by redundant and diverse communication links (Joint Chiefs of Staff, 2012).

At sea, the Navy relies on the full integration of MILSATCOM and COMSATCOM in order to perform its global presence mission. The continued procurement of more COMSATCOM by the DOD is critical in order for the Navy to not only support the current operational requirements but to be postured for rapid response to future crisis. About 60 percent is used every day worldwide; the other 40 percent is sitting out there as surge that is bought ahead of time when the Navy repositions ships to an area where bandwidth is needed (C. Racoosin, classroom lecture, August 19, 2014). In 2009, this provided a total of 258 megabits per second throughput for the entire naval fleet.

From Fiscal Year (FY) 2010 to FY 2011, DOD COMSATCOM procurement cost increased from $990 million to $1.216 billion (C. Racoosin, classroom lecture, August 19, 2014). The additional $226 million in FY 2011 was the total of the combined cost increase in total satellite services. Fixed satellite services (FSS) expenditures increased 30 percent from $673 million in FY 2010 to $875 million in FY 2011; as well as, DOD's bandwidth usage increased 15 percent (C. Racoosin, classroom lecture, August 19, 2014). The DOD's traditional primary investment in FSS was due in part to its high throughput capacity using relatively stationary terminals; as opposed to mobile satellite services (MSS) comparatively lower throughput capability over mobile ground terminals. In FY 2011, MSS expenditures consumed 27 percent of the total DOD COMSATCOM budget, which equated to an 8 percent increase from FY2010 ($304.2 million) to FY2011 ($328 million) (U.S. Strategic Command, 2013).

The recent decade-long conflict highlighted a need to increase capabilities for disadvantaged users whose growing requirement to receive, process, and disseminate information relied on an antiquated communication asset that interfaced solely with MSS. Consequently, the demand for higher bandwidth capable smaller portable ground receivers emerged. The physical size distinction is becoming less relevant today as smaller, portable terminals support FSS band frequencies; as well as, MSS solutions increasingly provide higher throughput capacity (U.S. Strategic Command, 2013). These highly capable portable terminals are able to be outfitted with smaller and smaller antennas.

The introduction of highly mobile smaller ground terminals capable of accessing higher band frequencies normally associated with FSS (C, Ka, Ku, and X) addressed the growing requirement to disseminate high bandwidth consuming products to/from the tactical level. In particular, as shown in Figure 3, Ka band operates between the 26.5 GHz and 40 GHz range of frequencies allowing for higher bandwidth allocation for deployed forces (C. Racoosin, classroom lecture, August 19, 2014). Expeditionary forces using portable ground receivers such as the PRC-117F/G were able to push/pull data products via Ka-band at higher rates of speed.

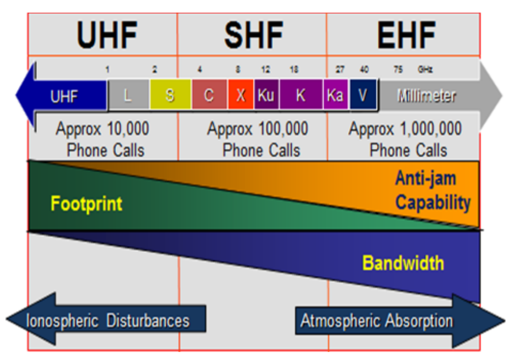


Figure 3. Ka-Band Capability and Trends (from C. Racoosin, classroom lecture, August 19, 2014)

2. Information Dissemination Trends

The concept of delivering C4ISR to the tactical edge has been explored by the military and commercial industry in an effort to enhance the capabilities of users in a DIL environment. The DOD observed during the recent wars that demands levied on small units and its leadership created situations where the timely delivery of information was the difference between life and death. As portrayed in Figure 4, the information collection requirements grows exponentially up the chain of command requiring edge units to use multiple disconnected systems to meet the requirement.

> Power to the Edge is a result of technological advances that will eliminate the constraint of bandwidth, free us from the need to know a lot in order to share a lot, unfetter us from the requirement to be synchronous in time and space, and remove the last remaining technical barriers to information sharing and collaboration. (Alberts & Hayes, 2003, p. xiii)

Information Across Echelons

MEF Division	Insatiable requests for information from above (including ISAF)
Regiment Battalion Company	Overloaded by higher HQ RFIs, lots of powerpoint-based reports requiring data from large servers; they get and synthesize significant info from below; pattern analysis across a large battle space
Platoon	Little info flows downhill; High density of disparate systems that require extensive training; some reliance on commercial products (e.g., Garmins, Ipads, Google Maps, etc.)
Squad	Protected from higher HQ info request. Didn't necessarily get a lot of info and hence didn't expect it. Primarily worked voice.

Figure 4. Information Flow Up/Down USMC Echelons of Command (from Naval Research Advisory Committee, 2012, p. 6)

Throughout the years, the DOD implemented several concepts in order to overcome the information dissemination limitations that lightweight highly mobile users faced when deployed to tactical environments as represented in Figure 5.

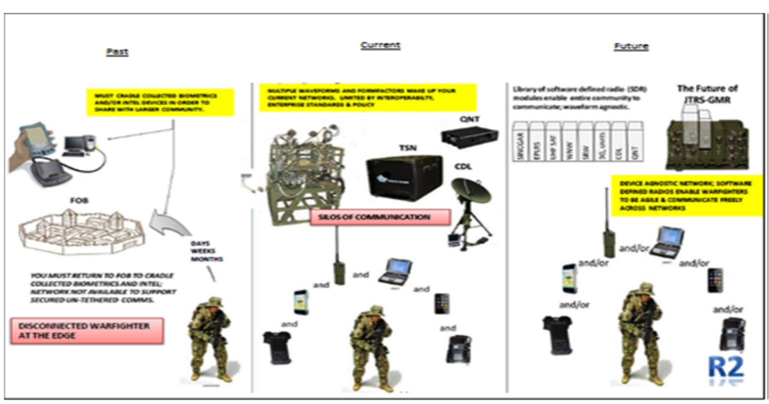


Figure 5. Maturation of Warfighter Communication Capabilities (from Liguori & Daniel, 2013, p. 27)

With the initial primary focus on the delivery of information, the DOD adopted the smart push concept. This concept empowered the owner of the information and relied on the owner's judgment when deciding what information is important to whom. This concept faced bandwidth and throughput challenges; as well as, time synchronization challenges when advantaged users attempted to correspond with disadvantaged users. The smart push required that the recipient had to be listening at the exact point in time in which the sender was transmitting as well as close enough for the equipment to remain synchronized.

Further technological advancements in communication equipment improved range limitations and introduced the broadcast capability in the smart push. This allowed commanders to distribute forces to the tactical edge and push information to them through mobile listening devices without concern for spatial proximity. The problem of knowing what information to send and the requirement for the edge unit to be available in a dynamically changing environment to receive it was not addressed until the advent of the email system. This technological breakthrough eliminated the need to maintain complete synchronization; however, the sender was still required to decide what information was important to the people that relied on it.

Finally, network connectivity and shared information resources enabled the migration to smart pull; this removed the owner-to-requestor time synchronization and the need for information owners to know exactly what is needed and how to get it to the requesting party (Alberts et al., 2003, p. xiv). This concept shifted the problem that was associated with the smart push in the sender-to-receiver relationship. The owner of the information was no longer responsible for time synchronization with the intended recipient. Although smart pull is described as an improvement to the smart push concept, this method of information dissemination presents its own set of problems. Operating under the smart pull construct, the actor that needs actionable intelligence is now required to know: a. the location of all the gathered sources of raw data in order to perform operational/intelligence fusion or b. the location of the resultant processed valuable information and when it was generated. Now, the commander is responsible for determining what information is critical for mission success. Unfortunately, this capability is not possible since the commander is unable to anticipate the composition of the fused information as this process is dynamic and based on anticipated events and state changes. Instead, the responsibility is assigned to the intelligence fusion center (IFC), where analysis is performed across diverse sources of information in order to produce the requisite knowledge needed to support mission sets. The IFC eliminates the requirement for the tactical edge units to obtain, train, and equip a data fusion cell tasked with finding the relevant information among all the available information; especially since, the commander is unaware of the origin and the type of sensors that were used in order to gather the raw data (Naval Research Advisory Committee, 2012).

3. DOD Information Technology Focus

DOD has explored ways to remove the general computing resources from devices that are supporting edge users to somewhere else in the network in order to alleviate the saturation of scarce computing capacity. Alberts et al. (2003, p. 192) stated "a dismounted infantry-person's information resources could be a thin client dedicated to supporting a rich human-computer interface [with voice recognition, heads-up display, speech synthesis, and communications]" (Alberts et al., 2003, p. 192). With the end goal of increasing capability to the edge user, DOD has conducted experiments with cloud computing to identify and mitigate network issues in expeditionary units in deployed environments. Since 2012, the U.S. Army has tested and evaluated the feasibility of delivering increased C2 capability to the tactical edge using a cloud-based platform (Welsh, 2012).

According to Powell (2013, pp. 6–7), the tests were designed to eliminate the prevailing degradation of network connectivity that Soldiers experienced once they transitioned from a garrison network to a tactical network. The intent is to leverage technology and develop a strategy using cloud computing that will revolutionize C2 down to the tactical edge by employing high computing capacity smart hand-held devices. This would provide the edge units with the agility needed, as Kundra's Federal Cloud Computing Strategy (2011, p. 5) stated, to spend less time focusing on sustaining and maintaining highly intricate communication equipment and more time dedicated to mission essential tasks. Removing the requirement to perform network management at the tactical level through the use of user enabled discriminatory access to shared infrastructure presented an appealing case to the DOD CIO leadership. Traditionally, the focus was to deliver an IT capability that centered around an optimally configured hardware and software solution; however, the shift in mindset in the cloud computing model for providing IT as a service is concentrated on the user as depicted in Figure 6 (Office of the Department of Defense Chief Information Officer, 2012a, p. 2).

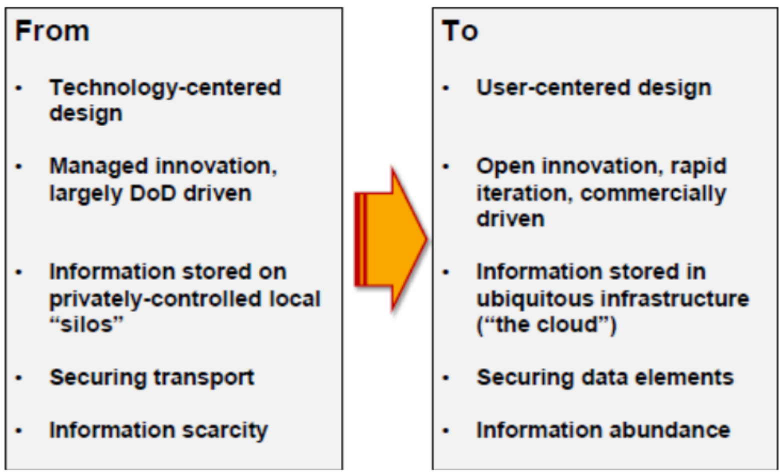


Figure 6. Shift in IT Focus (Naval Research Advisory Committee, 2012, p. 19)

4. Mobile Device Strategy for DOD

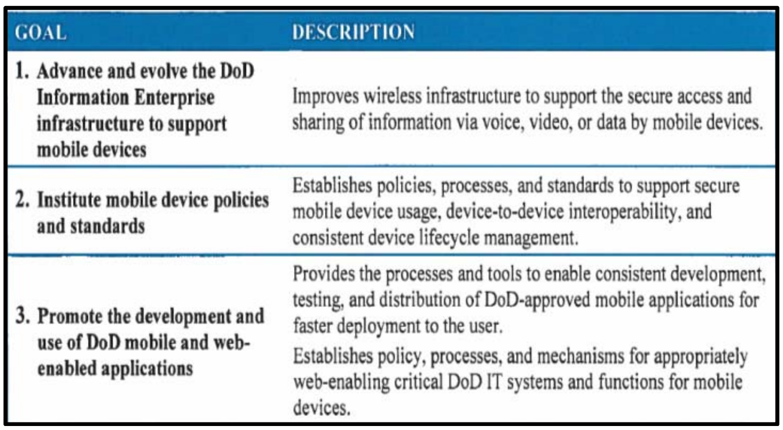
As the lead for developing policy and disseminating guidance to the Marine Corps Chief Information Officer, the DOD Chief Information Officer distributed the DOD Mobile Device Strategy that focused on "improving three areas critical to mobility: wireless infrastructure, the mobile device itself, and mobile applications" (Office of the Department of Defense Chief Information Officer, 2012b, p. i). These improvements are essential to empowering deployed personnel with faster access to information and computing power in spite of their geographical dispersion (Office of the Department of Defense Chief Information Officer, 2012b, p. i). One approach to achieving this goal requires focusing on the fourth critical area absent in the DOD CIO guidance to the Marine Corps CIO which is to ensure persistent connectivity between the cloud and the mobile device though the use of cloud technology and cloudlets. Cloudlets are tactically forward deployed well-connected datacenters in a box that are positioned at the tactical edge for mobile device users operating in a DIL environment. Cloud technology and cloudlets are a viable conceptual option that provides "a reliable, high-bandwidth, end-to-end network" (Satyanarayanan et al., 2013, p. 40). The use of cloud technology and cloudlets would eliminate the inherent latency edge users experience as they attempt to retrieve critical information in real-time. In addition, the benefits provided by implementing cloud technology and cloudlets would enhance the tactical unit's ability to operate mobile devices in a contested environment. The effects of an enemy's attempt to perform denial of service (DoS) attacks through wireless jamming is minimized due to their (cloudlet and mobile device) close proximity and wireless technology (ultra-short-range) employed.

In order to ensure all components of DOD were focused in the development efforts toward the same end goal, the DOD Mobile Device Strategy provided the following definition:

> A mobile device is a handheld computing device with a display screen that allows for user input. When connected to a network, it enables decision making via collaborative planning in forms formats specially designed to maximize the use of information given device limitations. Popular model designs for mobile devices are smartphones and tablets. (Office of the Department of Defense Chief Information Officer, 2012b, p. i)

Although information sharing is important, the real value of the mobile device is achieved when it is able to incorporate the tactical warfighter in the D2D process. Using the persistent connection to the cloudlet, the edge user can use the hosted sensor applications on the mobile device to conduct battlefield assessments in support of BFSA; as well as, receive intelligently fused information needed to perform last-mile re-planning. Leveraging mobile device, cloud, and cloudlet technology for the aforementioned military application would facilitate decentralized C2; as well as, autonomous decision-making at the edge (Reddy, 2012).

Due to their relatively inexpensive nature, mobile devices have provided much of today's mobile society with an on-demand information obtaining capability. As such, the DOD intends to leverage mobile device capabilities and employ them in ways to improve tactical operations. The recent use of mobile devices by organizations to provide information in support of global situation awareness during events such as natural disasters; serve as example use cases for testing mobile devices in expeditionary environments (Office of the Department of Defense Chief Information Officer, 2012b). As described in Figure 7, the DOD intends to evolve the enterprise by strengthening the DOD workforce through mobile device integration; along with developing and employing web-enabled applications.



GOAL	DESCRIPTION
1. Advance and evolve the DoD Information Enterprise infrastructure to support mobile devices	Improves wireless infrastructure to support the secure access and sharing of information via voice, video, or data by mobile devices.
2. Institute mobile device policies and standards	Establishes policies, processes, and standards to support secure mobile device usage, device-to-device interoperability, and consistent device lifecycle management.
3. Promote the development and use of DoD mobile and web-enabled applications	Provides the processes and tools to enable consistent development, testing, and distribution of DoD-approved mobile applications for faster deployment to the user. Establishes policy, processes, and mechanisms for appropriately web-enabling critical DoD IT systems and functions for mobile devices.

Figure 7. DOD Mobile Device Strategy Goals (from Office of the Department of Defense Chief Information Officer, 2012b, p. 1)

5. Mobile Device Strategy for USMC

In 2013, the Director for Command, Control, Communications, and Computers (C4), Brigadier General Nally stated "with increasing mobile device capabilities, the Marine Corps recognizes the trend of evolving information needs within garrison and tactical environments and the need to provide an agile method of meeting those needs" (Director for Command, Control, Communications, and Computers (C4), 2013). Just as the DOD wants to untether the workforce from the desk in an office by enabling the end user—equipped with a mobile device—to maintain connectivity to shared information and computing power without degradation of capability, the Marine Corps desires to remove the overreliance on the stationary ground satellite located at the FOB. Currently, edge users experience a degrading autonomous decision-making capability as they transition from a fixed location; to vehicle-borne; to foot-mobile. The increased ability for highly mobile users to access, share, and manipulate knowledge enhances their capability to deduce courses of actions in support of FOA and FOM (Director for Command, Control, Communications, and Computers (C4), 2013). In spite of geographical location, mobile devices would enable key leadership collaboration among throughout the planning process for contingency and crisis operations order development as illustrated in Figure 8. The global distribution of actionable intelligence to decision-makers reduce the time required in the D2D cycle (Director for Command, Control, Communications and Computers (C4), 2013).

Figure 8. Marine Corps Planning Process (from Marine Corps Combat Development Command, 2008)

In a fiscally constrained environment, scarce resources are focused on user requirements and technology improvements that will affect more rapid mission accomplishment. The individual user and the user requirements have been a driving force in the shift of focus. In order for the Marine Corps to successfully implement the Commercial Mobile Device Strategy, the following four goals must be met: "1) Establish a Secure Mobile Framework; 2) Transition the Unclassified Mobile Device Infrastructure to a Cost Effective and Platform Agnostic Environment; 3) Collaborate with DOD and Industry Partners to Develop a Classified Mobile Device Capability; and 4) Incorporate Personally Owned Mobile Devices" (Director for Command, Control, Communications, and Computers (C4), 2013, p. 3).

a. USMC Guidance

The Marine Corps recognized that fused intelligence products are a prerequisite to the D2D process. There exists a need to improve the user decision centricity capability at the tactical edge in order to promote independent and real-time response when operating in a dynamic environment. This will assist the Marine Corps in remaining capable of operating as a decentralized expeditionary force. The continued emphasis toward improving the C2 capability at the lowest level is essential to the operational posture of a mobile force. MCDP-6 states:

> No single activity in war is more important than command and control. Command and control by itself will not drive home a single attack against an enemy force. It will not destroy a single enemy target. It will not affect a single emergency resupply. Yet none of these essential warfighting activities, or any others, would be possible without effective command and control. Without command and control, campaigns, battles, and organized engagements are impossible, military units degenerate into mobs, and the subordination of military force to policy is replaced by random violence. In short, command and control is essential to all military operations and activities. (U.S. Marine Corps, 1996, p. 35)

Marine Corps Combat Development Command (MCCDC) (2013) stated C2 consists of personnel, information, processes, and the logistical support which enable actionable intelligence from the collection and analysis of raw data. MCCDC's guidance was to migrate from a focus on the system of systems (SoS) capability in favor of a decision-centric user focused network enabled C2 capability that supported decentralized and distributed Enhanced Company Operations (Marine Corps Combat Development Command, 2013).

b. Naval Philosophy

After prolonged land based wars in Iraq and Afghanistan, the Marine Corps' maritime strategy reaffirmed its commitment to a fully integrated naval capability (Conway, 2008, p. 9). Forward thinking, the Marine Corps' future modernization programs for communication equipment and weapon systems are being designed to increase the capacity for expeditionary forces to conduct ship to shore operations (Conway, 2008, p. 9). Sea based tactical units, conducting initial operations without external host nation support in underdeveloped harsh environments, are capable of strategic power projection in defense/support of U.S. allies in contested regions (Conway, 2008, p. 10). Navy Tactical Reference Publication 1–02 (2012) defines sea base as

> an inherently maneuverable, scalable aggregation of distributed, networked platforms that enables the global power projection of offensive and defensive forces from the sea and includes the ability to assemble, equip, project, support, and sustain those forces without reliance on land bases within the joint operations area. (U.S. Navy, 2012, p. 2–74)

The maneuverability and agility afforded by operating from sea is nullified by legacy communication equipment incapable of keeping pace with the information collection and dissemination demands necessary for shared situation awareness between the at Sea Commander and the Ground Force Commander. In an effort to eliminate the information disconnect between forces, the Navy and Marine Corps have developed the Single Naval Battle Concept.

An essential component of the Single Naval Battle Concept is an inter-service commercial applications based cloud topology (Naval Cloud) that leverage innovative technology (Naval Research Advisory Committee, 2012). As shown in Figure 9, the Marine Corps' recognition of the benefits gained by using mobile device applications—coupled with the flexibility and scalability of cloud technology—has generated specifications designed to enhance information dissemination to the disadvantaged user (Naval Research Advisory Committee, 2012). Successful implementation will support the facilitation of information aggregation and delivery requirements placed upon mobile commanders operating in DIL environments.

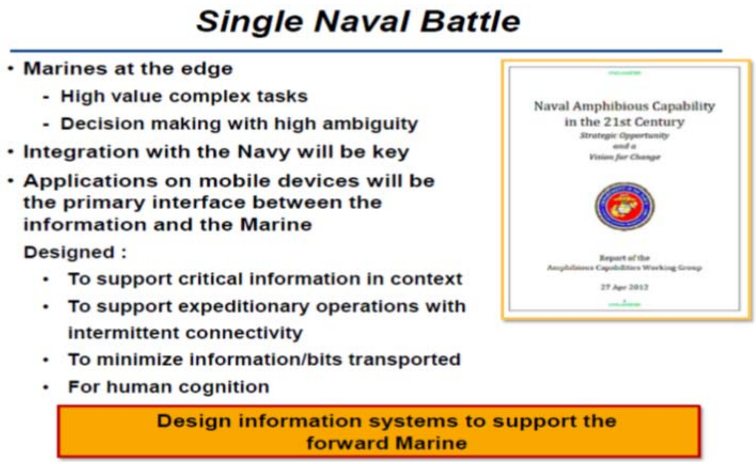


Figure 9. Single Naval Battle Concept (from Naval Research Advisory Committee, 2012, p. 15)

Marine Corps focused mobility requirements—such as smart reduction of the information that needs to be transported—must be identified in mobile device capability development. There are two factors that must be considered: a. the limiting resource is bandwidth and b. extracting and taking the most valuable information forward. One approach is to automatically summarize information based on its prioritization through the use of self-aware transport middleware. By being aware of dynamically changing bandwidth, this device could provision information at different levels of granularity while optimally using available network bandwidth. For example, edge users operating in a DIL environment further degraded by A2AD threats still have requirements for meteorological and oceanographic (METOC) data. Although normally viewed in a bandwidth intensive high resolution state, a self-aware transport middleware would adjust for current bandwidth conditions/priority and display a lower resolution METOC product in order to ensure the warfighter received something.

> In spite of capturing and adapting commercial advances as well as leveraging the work of the Army NETT Warrior initiative, Marine Corps strategy and operating concepts must involve special considerations and constraints for information delivery to the 'Marine on the move', which are unlikely to evolve from commercial or Army doctrine concepts. (Naval Research Advisory Committee, 2012, p. 11)

General Conway stated the future Corps will reestablish its naval presence at sea, remain a multipurpose expeditionary entity, and remain receptive to innovation and new technology (Conway, 2008, p. 19). This shift in focus from land-based occupation to a rapidly deployable agile force operating from ship-to-shore will require unique C4ISR capabilities similar to special operation forces (SOF). The Marine Corps is focused on integrating and delivering C4ISR down to the squad level to provide small unit leaders with the required knowledge needed to make critical autonomous decisions at decisive points in battle (Conway, 2008, p. 20). General Conway acknowledged the significant efforts made in the past decade to deliver this capability above the company level; however, emphasized its requirement below the company level due to current equipment limitations (Conway, 2008, p. 20). Due to the harsh operating environment at the tactical edge, legacy communication systems are inept at delivering these mission critical capabilities. As such, the Marine Corps confirmed its pledge to aggressively pursue integrated lightweight mobile devices that deliver V2D capabilities to the Marine at the edge (Conway, 2008, p. 20).

6. Capability Gaps

In the past, the priority for DOD was to deliver V2D capability to commanders at fortified FOBs via high bandwidth/throughput ground-based networked SoS. Effectively, the C4ISR assets increased the data fusion and analysis capabilities; as well as, increased the capacity of information that could be gathered and submitted to HHQ. Mobile users that conducted operations away from the FOB experienced an instant degradation in their ability to collect and report information vital to situation awareness due to unreliable, low data throughput, voice radio assets. “A reliable and robust information gathering and decision-support system cannot exist without the capacity to access, verify, and combine data and data products across multiple information types and sources” (Naval Research Advisory Committee, 2012, p. 9). In spite of this, the technically disadvantaged mobile user was still expected to feed the seemingly never-ending request for information from above by constructing bandwidth intensive high definition power point presentations that required a connectivity level resident at the well connected FOB.

Combat Development and Integration’s (CD&I) (2012) Concept of Employment (COE) for Infantry Company and Below C2 (ICB-C2) document identified a data capable mobile device need for enhanced company and below operations. As shown in Figure 10, COE for ICB-C2 identified a disparity in current equipment capabilities and stated the mobile device solution must have a common look and feel that enable a seamless transition through company employment conditions (fixed, OTM, and dismounted) without degradation of V2D services (Combat Development and Integration, 2012).

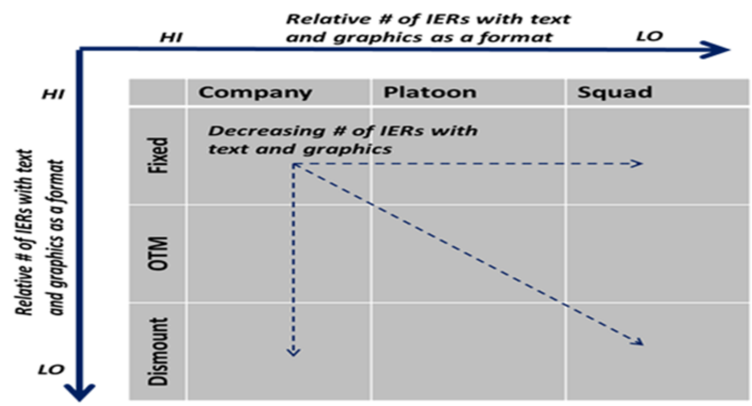


Figure 10. Company Level Information Exchange Requirements (IER) and Capabilities (from Combat Development & Integration, 2012, p. 27)

This lack in current capability attributed to a deficiency across the MAGTF to distribute BFSA and reliable blue force location updates down to the peripheral units (Combat Development and Integration, 2012). The document also stated untimely incomplete information flow from the decision makers at the company level and below to the squad level and above limited their (company, platoon, and squad) ability to validate targets and non-combat desired effects in near real time (Combat Development and Integration, 2012). One of the elements needed in order to engage an enemy combatant is positive identification. In a fluid environment, the time it takes to confirm the identification of a known hostile could result in a capture/kill or a missed opportunity to detain a fleeing potential suspect. Current system capacity limitations are inadequate for meeting the demands of mobile units (Combat Development and Integration, 2012). Also, the news of positive effects accomplished by U.S. service members in an area to thwart the aggressive actions of malign actors can spread to other areas resulting in an overwhelming shift in support for U.S. service members. Without this knowledge integrated into their mobile devices, U.S. service members are not able to capitalize on potential human intelligence. The aforementioned capability gaps could potentially be filled by a mobile device solution that effectively integrates information and technology in a disadvantaged environment as depicted in Figure 11.

Figure 11. Information and Technology Imperatives (from Naval Research Advisory Committee, 2012, p. 28)

C. EXISTING C2ISR REQUIREMENTS

Assisted by the headquarters staff, the infantry rifle company commander is responsible for conducting mission analysis and disseminating mission-type orders to subordinates (U.S. Marine Corps, 2014c). These vital tasks are performed without the benefit of an organic IFC or the equipment needed to collect/synthesis raw data in order to produce a tangible product for edge units to act upon. The infantry rifle company relies on the maneuverability and agility afforded by C2 to conduct offensive, defensive, amphibious, and stability operations as described in Figure 12.

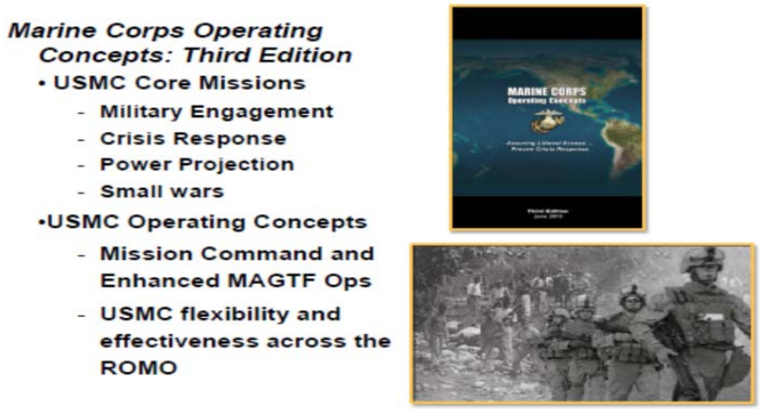


Figure 12. Full Spectrum Warfare Operations (from Naval Research Advisory Committee, 2012, p. 14)

The increased demand to use infantry companies as semi-autonomous modular forces over prolonged periods has placed an emphasis on C2 (Combat Development and Integration, 2012). The Marine Corps understands that commanders use C2 to determine what needs to be done, execute it, and then assess the aftermath; therefore, importance has been placed on providing infantry company commanders with increased capabilities to meet current C2 requirements (U.S. Marine Corps, 2014b). The next step in the evolution of the infantry company is to increase their capability to participate in collaborative collection management by fielding and assigning organic ISR assets to the TO&E. "Military excellence is defined by the excellence of our Marines; their thinking, ability to innovate, adapt, and to overcome the challenges presented by complex environments, threats, and conditions" (Deputy Commandant for Combat Development and Integration, 2010). This has led to situations in which a reinforced company with augmented C2 equipment from higher echelons has been tasked to broadcast BFSA in order to establish unity of effort among higher, adjacent, and subordinate forces (U.S. Marine Corps, 2014b). Through C2, the expectation of an infantry company's ability to maneuver throughout the battle space as required, execute kinetic and sustainment operations, and mass and deliver scalable fires capability has grown (Combat Development and Integration, 2012). Subsequently, the overarching mission of the end to end PaaS is to enable C4ISR for company and below units operating in all employment functions spanning the full range of military operations (ROMO) (Combat Development and Integration, 2012).

1. Equipment Capabilities

A key component to improving the C2 D2D cycle is the integration of non-interoperable SoS. The lack of interoperability among current stove-piped systems has placed an undue burden on the Marine Corps' and its ability to perform its mission (Marine Corps Combat Develop Command, 2007). Shared situation awareness is directly proportional to the interoperability and capabilities of systems used for C2. Commanders gain increased agility, common operational picture, and faster decision-making through mutual understanding (Marine Corps Combat Development Command, 2007). With the aim of supporting tactical level commanders in all three employment conditions (fixed, OTM and dismounted), the equipment must be confined in a space that is man-packable, ruggedized, multi-band capable, and communicates beyond normal speaking range without compromise of location and provide confidentiality (Yang, 2011). As depicted in Appendix G, each echelon of command concept of employment across the full spectrum of warfare under the three categories is directly tied to its current communication and C2 capabilities.

a. Fixed Capabilities

Employed at a stationary location, the Combat Operations Center (COC) provide the warfighter with C2, networking, and communication systems that support hosted applications unique to fires and maneuver, intelligence, logistics, and force protection (Combat Development and Integration, 2012).

(1) Company Fixed Combat Operations Center (COC)

MCRP 5–12C (2011b) defines the COC as the primary operational agency of a command by which assigned elements of the MAGTF are employed. Staffed with the requisite personnel and equipment, the COC receive and analyze information; issue orders; and supervise execution (U.S. Marine Corps, 2011b). The COC is designed to enhance lethality, improve C2, and overall mission effectiveness across ROMO (Marine Corps Combat Development Command, 2008, p. ES-2). As depicted in Figure 13, COC capability set (CAPSET) V nodes plug in to the information rich MAGTF Tactical Data Network through intermittent line of sight (LOS) connections over limited data throughput capacity communication devices (Marine Corps Combat Development Command, 2008).

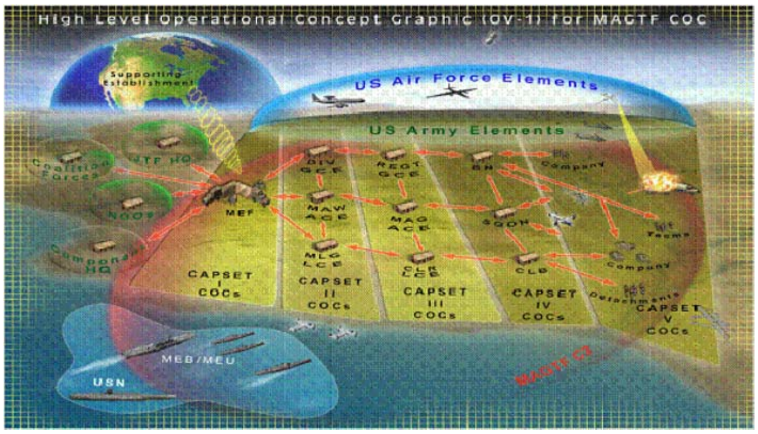


Figure 13. MAGTF C2 using COC Capability Sets (CAPSET) I–V (from Marine Corps Combat Development Command, 2008, p. ES-3)

As represented in Figure 14, the COC is intended to give commanders and staffs the ability to efficiently access current and previously stored fuse intelligence products and transmit tactical information across all mediums using a SoS networked architecture (Combat Development and Integration, 2012).

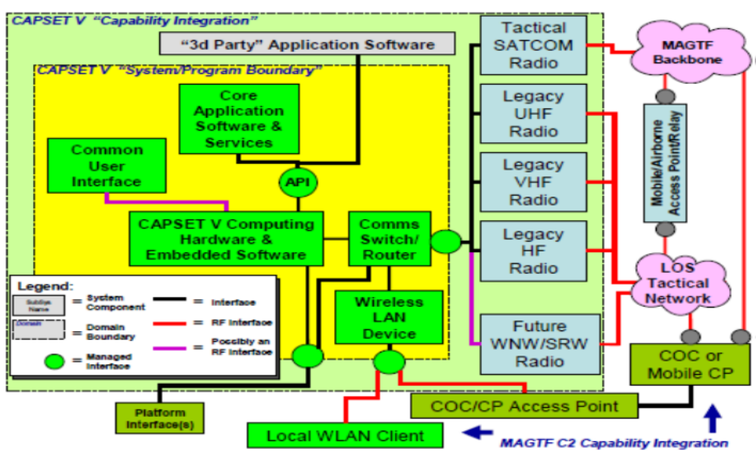


Figure 14. COC CAPSET V Network (from Marine Corps Combat Development Command, 2008, p. 63)

Dictated by the commander's mission needs, the company level fixed COC has a scalable configuration that can support the detailed planning and integration requirements of a main CP; as well as, an expeditionary forward CP (Combat Development and Integration, 2012, p. 21). As the requirements of the company determine the need for an enduring fixed operations center, all available assets to include manpack systems and additional stationary equipment will be used in support of the COC personnel IER detailed in Figure 15 (Combat Development and Integration, 2012, p. 23).

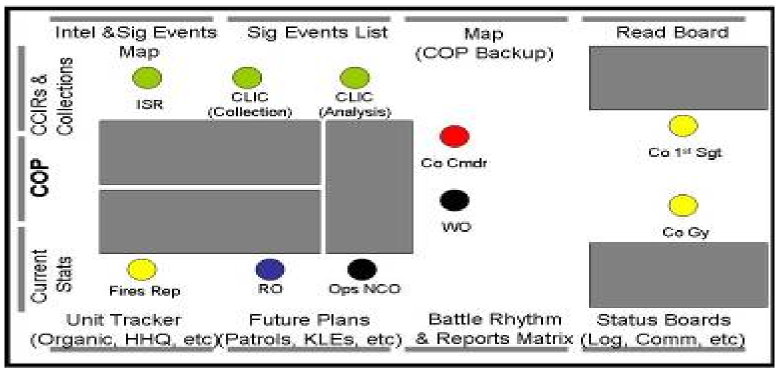


Figure 15. Notional Fixed Robust COC (from Combat Development and Integration, 2012, p. 23)

Fixed COCs operating out of the back of High Mobility Multipurpose Wheeled Vehicles (HMMWV) or Joint Light Tactical Vehicles (JLTV) with mounted tactical radios, manpack systems, and battlefield situation awareness provide commanders forward of the main COC position with C2 capabilities. As seen in the configuration in Figure 16, the vehicle-borne COC allows the commander to establish an alternate position and assume C2 responsibilities while the main COC displace and reestablish itself.

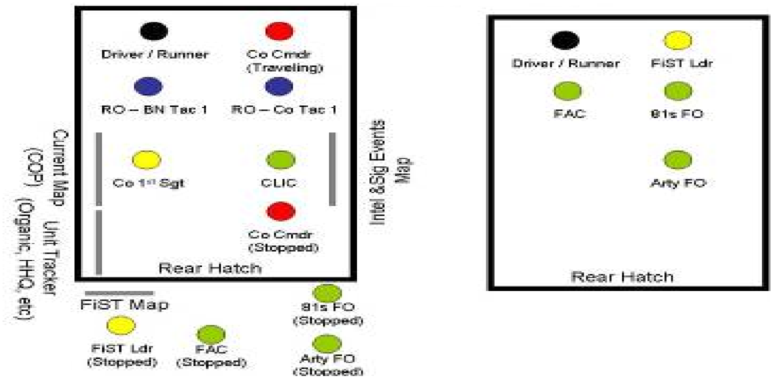


Figure 16. Notional Fixed Vehicle Forward COC (from Combat Development and Integration, 2012, p. 22)

The current fixed systems capabilities are described in Appendix F.

b. On-the-Move (OTM) Capabilities

Data and video communications OTM (DVCOTM) capability is essential for commanders to be able to maintain speed and aggression. Liguori et al. (2013, p. 40) stated a unit commander currently must decide between halting their assault in order to access real-time data and video for improved BFSA or continuing pursuit of the enemy with an update capability limited to legacy tactical voice. Voice alone has been inadequate in decreasing the time in D2D cycle. The ability for geographically dispersed maneuver units to access essential DVCOTM would improve decision-making and give companies an operational advantage over adversaries (Combat Development and Integration, 2012). A capability gap in legacy systems due to lack of additional resources to support operational maneuver units on the move is described in Appendix C.

(1) Company OTM Combat Operation Center (COC)

Current gaps in network capacity and throughput result in insufficient transport capacity while OTM. Mobility and resource constraints hinder the COC's design from being based on functional activities. The company COC configuration must not be so cumbersome as to degrade mobility; however, it must be robust enough to allow the commander to effectively direct and influence subordinate forces (Combat Development and Integration, 2012). Furthermore, dissimilar communication systems across the variety of weapon platforms an infantry company can be embarked upon dictate what vehicular

C2 assets are available OTM (Combat Development and Integration, 2012). As illustrated in Figure 17, tactical radio is the only means for the commander to remain connected to subordinate, adjacent, and higher forces while OTM.

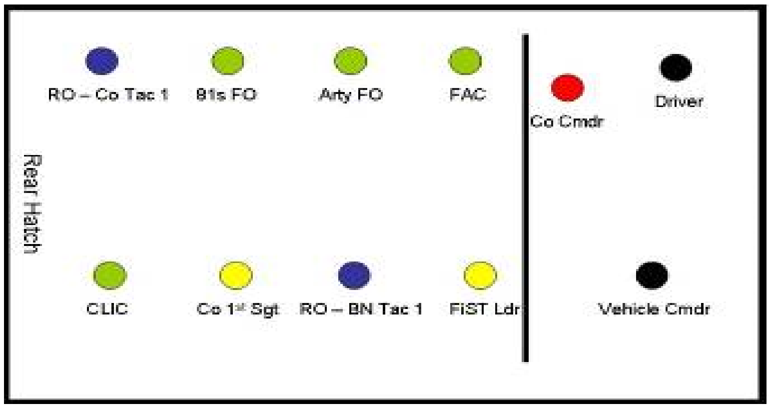


Figure 17. Notional OTM Amphibious Assault Vehicle COC (from Combat Development and Integration, 2012, p. 20)

The current OTM vehicular systems capabilities are described in Appendix E.

c. Dismounted Capabilities

Communication systems provide the mobile tactical unit situation awareness and C2 during enemy engagement. Vehicleborne patrols are ideal for covering large geographical areas; however, terrain limitations can necessitate the need for foot mobile operations into an otherwise denied access area. If the IER calls for the use of limited data or a BLOS capability, then one of the man-packed or handheld variants of the PRC family of radios will be tasked to fulfill the mission requirements. Specifically, multiband radio systems such as the PRC-117F/G are C2 force multipliers due to their ability to enable long-haul data and voice exchange (Combat Development and Integration, 2012).

(1) Company Dismounted Combat Operations Center (COC)

As shown in Figure 18, the mission may dictate the formation of a foot-mobile COC configuration. Immediately, edge units’ access to enterprise resources is degraded and their primary means of communication while in motion is the IISR.

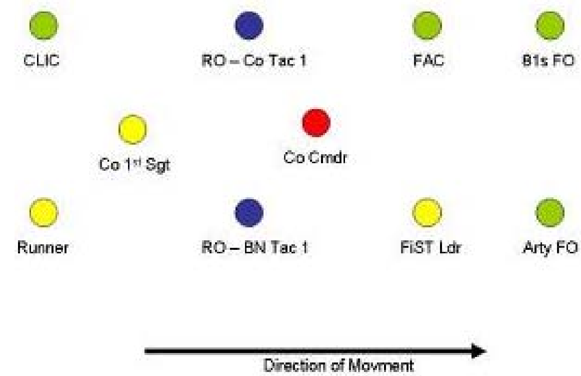


Figure 18. Footmobile COC (from Combat Development and Integration, 2012, p. 25)

The small, lightweight (~ 2.6 lbs) IISR was designed to provide C2 capabilities to the infantry squads and fire teams in tactical situations where other forms of communication were not feasible (U.S. Marine Corps, 2010b, p. 69). The IISR is a voice only radio that "acts as a wireless intercom" system (U.S. Marine Corps, 2010b, p. 69). The gap in data capabilities are overcome by the use of the PRC-117F/G. Unlike the IISR voice only capability, the PRC-117F/G provides the tactical edge user with voice and limited data throughput capabilities. Effectively eliminating the continuous mobility of the dismounted COC, the PRC-117F/G and its SATCOM antenna must be set up and remain stationary throughout the duration of its operation as depicted in Figure 19. The BFSA advantages gained from having access to data has resulted in the carrying of both radio systems when missions require the infantry company to disperse subordinate platoons and squads throughout their assigned AOR (Combat Development and Integration, 2012).

Figure 19. PRC-117F SATCOM Employment (from Public Affairs Office of the New Jersey Department of Military and Veteran Affairs, 2009, p. 28)

D. FUTURE CONCEPTS AND MANDATES

The IER of the expeditionary warfighter requires a DaaS/PaaS that provide V2D capability without a combat load increase to the user. As Coakley (1992, p. 79) pointed out, the problem is the "C2 equipment designed to sharpen a combat unit's 'teeth' also tends to swell its support 'tail'." Commander's outfitted with enhanced C4ISR capabilities also require an increase in specialized trained operators and maintenance personnel (van Creveld, 1985, p. 239). Critical to this is the acquisition of C2 systems that improve upon and interoperate with legacy C2 systems. Leveraging emerging technology that provides battlefield situation awareness reduces uncertainty and assists the commander with knowledge perception. The DaaS/PaaS requirement is the successful integration of transmission systems, networking systems, applications, and end-user devices that eliminates a degradation of capability as the warfighter traversed the employment functions (fixed, OTM, dismounted) (Combat Development and Integration, 2012).

1. Cloud Platform Solution

In Appendix K, the National Institute of Standards and Technology (NIST) described three service models for delivering an IT. Cloud platforms provide a way to distribute state-of-the-art, effective, and secure C4ISR capability to an edge user's mobile device (Office of the Department of Defense Chief Information Officer, 2012a, p. E-1). Unfortunately, mobile devices are resource-poor due to physical limitations that inhibit maximizing computational capabilities. As stated by Satyanarayanan M., Bahl, P., Caceres, R., and Davies N. (2009, p. 3) "a mobile device could execute a resource-intensive application on a distant high-performance compute server or compute cluster and support thin-client user interactions with the application over the Internet." This can be achieved by connecting the mobile device to a resource-rich well-connected cloudlet; ultimately, providing the edge user with critical real-time fused intelligence products at their fingertips. A need for the aforementioned and alike capability results in the warfighter generating requirements for the PaaS infrastructure layer resulting in fielded integrated C4ISR applications that are tailored to various mission sets. Applications such as facial, speech, and language recognition provide credibility in claims of nefarious acts performed by an assailant. In order for these resource intense applications to provide real-time interactive response to tactical edge units, there exist a need for "low-latency, one-hop, high bandwidth wireless access to the cloudlet" (Satyanarayanan et al., 2009, p. 6).

In addition to the service models described by NIST, DaaS is viewed as an enabling layer for the PaaS layer since it is a collection of data services that are interfaced from the PaaS model. DaaS is a form of cloud computing service that uses application programming interfaces (API) to deliver data on demand to consumers; however, it does place a concern on the quality of data and the data life cycle as seen in Table 1 (Vu, Pham, Truong, Dustdar, & Asal, 2012, p. 605).

Table 1. DaaS Capability Concerns (from Truong et al., 2009, p. 90)

Quality of Data	Timeline	Describes the lifetime of the data
	Up-to-date	Indicates the lag time of the of the data up to the current time
	Completeness	Describes whether the data has missing values
	Granularity	Describes the degree of data granularity
Data Life cycle	Backup/Recovery	Describes whether and how the data will be backed up, and to which degree and how long the data can be recovered if the data was lost
	Distribution	Describes whether the data will be distributed externally
	Disposition	Describes whether the data will be relocated or retained according to defined or lawful policies

The benefit of a local DaaS/PaaS model at the company level to the mobile warfighter is adding flexibility to the requirement to retrieve and store massive data stores on the edge device. With local DaaS/PaaS model it will become possible to perform subsequent searches for the needed time sensitive information critical to D2D process by incrementally updating data views stored in a device knowledge cache with incremental events stored at the local DaaS/PaaS model. This is performed during the execution of the same query or simple retrieval. DaaS/PaaS model provides the desired data through the use of query and "call the corresponding APIs to retrieve the data" (Vu et al., 2012, p. 605), as seen in Figure 20.

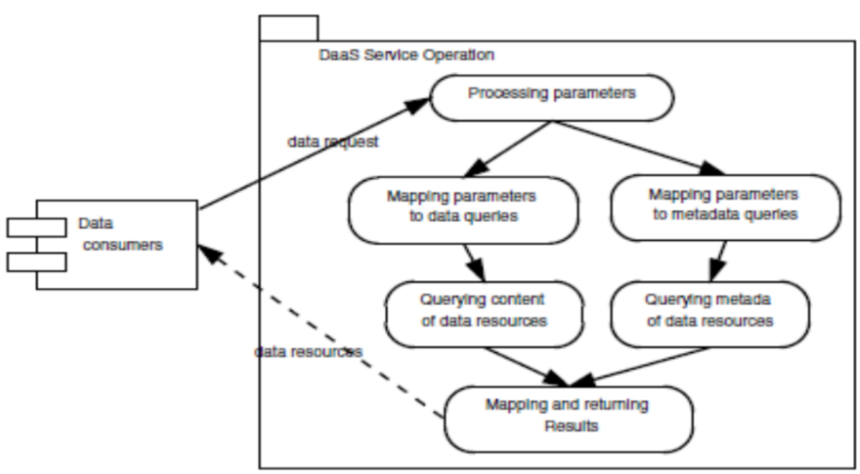


Figure 20. DaaS Service Operation (from Truong et al., 2010, p. 365)

This data can either be static with little to no change (e.g., an alpha roster of currently assigned personnel) or it can be volatile with constant changes (e.g., sensory data collected for the conduct of BFSA). The create, retrieve, update, and delete CRUD capability found in DaaS pose concerns about data sources and service context as outlined in Table 2 and Table 3.

Table 2. Data Management Concerns in DaaS
(from Truong et al., 2009, p. 91)

Name	Describes where the data is obtained
Size	Describes the volume of the data
Timespan	Describes the time duration in which the data is collected
Update Frequency	Describes how often the data is updated
Meta-data	Describes domain-specific standards that the data follows

Table 3. Service/Mission Context Concerns in DaaS
(from Truong et al., 2009, p. 91)

Location	Describe where a DaaS is hosted
Service Type	Describe whether the service is based on SOAP or REST
Level of Service	Describes whether the service is best effort or guaranteed
Data Classification	Describe the taxonomy characterizing the data provided by the service

In spite of these concerns, company and below BFSA are enabled by the data creation and retrieval capability. As edge users actively evaluate the dynamically changing landscape, they rely on all available sensor mechanisms (vision, smell, hearing, and touch) to shape their physical world model (PWM). The accumulation of data is processed by the human mind and creates a cognitive world model (CWM). Both PWM and CWM work in concert and constantly update in response to changing environmental factors. This combination has been the traditional means by which warfighters have operated in contested DIL environments. The successful integration of C4ISR at the tactical level enables integrating devices with computational processing power capable of performing retrieval and queries. Retrieval occurs when the requestor knows the location of the metadata. Query-retrieval process is when exploitation is performed by the requestor, using a meta-data management tool, to discover the meta-data and then followed by retrieval based on known meta-data.

The presentation of the digital world model (DWM) on a mobile device will either compliment PWM/CWM or contradict them. In the event of a contradiction, advanced analytics is required to exam the existing discrepancy(s). The DWM graphically displayed should be the result of a properly designed extract, transform, and load (ETL) system. "ETL is the process of extracting data from homogeneous or heterogeneous data sources, transforming the data for storage in the proper format or structure for querying and analysis purposes, and loading the data into the final target – such as a database, data store, data mart, or data warehouse" (Taft, 2015). The edge user with all three models has the constant ability to analyze the fluid environment and reduce the unknowns.

2. Requirements for Current Alternative Technologies

As detailed in Figure 21, Naval Research Advisory Committee (2012, p. 13) determined continuous innovation in new technologies is needed to meet the future demands of the tactical unit's IER. With the ever increasing threats to security in a fluid and changing environment, the warfighter requires access to intelligently fused shared information that is survivable against cybersecurity threats. The focus is on an enterprise end-to-end architecture that will "improve the user's ability to share information on architecture content; enable rapid access to actionable information to support strategic decisions; and increase agility to address unforeseen requirements supporting warfighting needs" (Office of the Department of Defense Chief Information Officer, 2006, p. 3). The DOD CIO does not address the increased requirement to share information across security levels as in the case of ISR dissemination. Successful C2 requires integration with ISR in order to provide the decision-maker with SA.

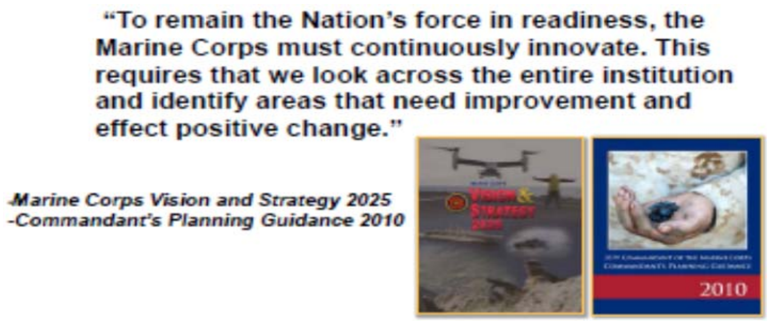


Figure 21. Future Force Implications (from Naval Research Advisory Committee, 2012, p. 13)

Future C2, as described by Marine Corps Combat Development Command (2013), will be performed by highly decentralized geographically distributed nodes in a dynamically fluid environment able to convey commander's intent. Addressing the current shortcomings of existing equipment capabilities, new systems are expected to provide LOS, OTM, and BLOS connectivity that creates a common operational picture between dispersed commanders vertically and horizontally linked as shown in Figure 22 (Marine Corps Combat Development Command, 2013). Furthermore, they must include the necessary transmission systems and communication architecture for edge units to access voice, text, graphics, or video sources located at the upper echelons in order to satisfy their IER (Combat Development and Integration, 2012).

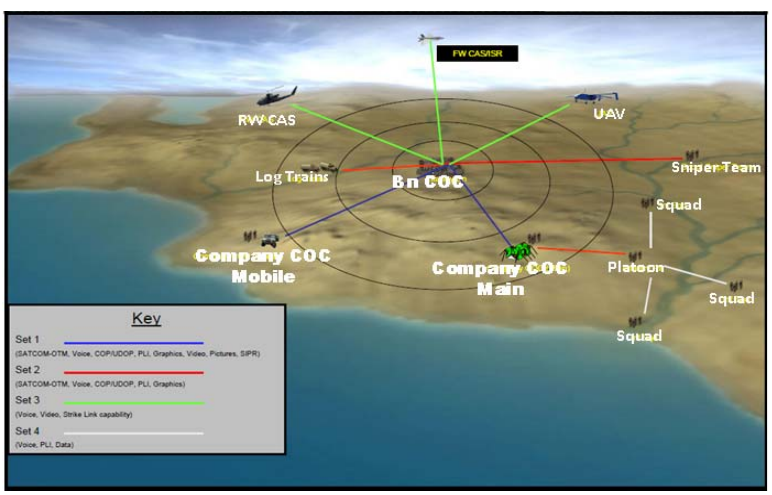


Figure 22. Future Design for Company C2 Capabilities (from Combat Development and Integration, 2012, p. 18)

According to the NIST Definition of Cloud Computing, a cloud computing infrastructure has the following critical characteristics: "on-demand self-service; broad network access; resource pooling; rapid elasticity; and measured service" (Mell & Grance, 2011, p. 2). The continued focus needs to remain on enhanced data-centric communication systems that extend C2 applications to the peripheral tactical locations operating at long ranges away from the enterprise communication hub (Combat Development and Integration, 2012). "In addition, this type of network architecture will provide a common computing environment that will provide cross-device interoperability – with the apps providing interoperability and standardization" (Naval Research Advisory Committee, 2012, p. 25). Depicted in Appendix L, the USMC MAGTF C2 Roadmap outlined the major characteristics of future communication systems that will enable the future vision of C2.

E. CHAPTER SUMMARY AND TRANSITION TO REQUIREMENTS ANALYSIS

This chapter has demonstrated three major themes:

- IER have revealed gaps in current capabilities as denoted previously in capability gaps
- Current C2 capability requirements have surpassed existing equipment capabilities
- Investing now in cloud technologies in support of disadvantaged users at the tactical edge to operate in a decision making role, even under D-DIL condition is essential to meeting the C2 requirements of the future

The perceived gap in a tactical edge unit's BFSA and C2 ability due to the degradation of V2D equipment capability and accessibility when deployed in the following conditions: fixed—OTM—dismounted require an analysis of a future alternative. Chapter III will analyze and compare current equipment capabilities with a PaaS and mobile device equipment solution.

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III. REQUIREMENTS AND ANALYSIS

The current operating environments for which company level communications take place leverage multiple communication assets to meet the needs of an information saturated environment. The assets provide key communication links to subordinate and higher echelon units and decision makers allowing for quicker responses which could prevent loss of life. According to the 2014 USMC Total Force Structure Management System Unit TO&E Report, Marines assigned to an Infantry Company are outfitted with 176 Personal Radio Communications (PRC) 153 integrated intra-squad radios (IISR), two Army Navy Vehicle Radio Communications (AN/VRC) 110s, one AN/VRC-114, four Army Navy Personal Radio Communications (AN/PRC) 117G(V)2s, and six AN/PRC-117F(V)1C (U.S. Marine Corps, 2014c). These assets provide very specific capabilities and when combined in different operating configurations, provide the company and below with capabilities with limited effectiveness due to distance and environmental conditions. The different operating configurations consist of fixed, OTM and dismounted operating environments. In reference to Appendix G, certain form factors are used for the varying array of operating structures in regards to the company, platoon and squad. Each configuration leverages the aforementioned communication assets to provide reliable communications for C2 and assist decision makers.

A. COMPANY COC FIXED, OTM AND DISMOUNTED

According to section 6.1.1.2 of the COE for ICB2, "The company COC is configurable depending on the mission and commander preferences, which includes consideration for the required COC personnel and the associated systems" (Combat Development and Integration, 2012). With this in mind, the company COC can be prescribed as aforementioned based on several factors obtained from intelligence or based on requirements given for the mission. Accordingly, a company will employ manpack, vehicle and stationary communication systems to meet the requirements in place by the company or battalion commander but are limited to the specifications of the communication asset. In accordance with the company guard chart, various channels are needed for C2 such as Tactical Net One (TAC1), TAC2, Company Command Net (CO CMD), Battalion (BN CMD), Fires, Safety and Intelligence (Intel). An example of a company guard chart is provided in Figure 23.

LEGEND: C – NET CONTROL X – GUARD A – AS REQUIRED W – WHEN DIRECTED **TRANSMISSION TYPE:** 1 – HF 2 – HF TACCHAT 3 – VHF 4 – UHF-SATCOM 5 – UHF	CO TAC 1	CO TAC 2	CO CMD 1	1ST PLT CMD	2ND PLT CMD	3RD PLT CMD	SAFETY	INTEL	FIRES		BN CMD
TRANSMISSION TYPE	3	3	2	3	3	3	3	4	3		2
PARTICIPATING UNITS											
BN X			X								C
Company X	C	C	C	X	X	X	X	X	X		X
Platoon 1	X	W	W	C	A	A	A	A	A		C
Platoon 2	X	W	W	A	C	A	A	A	A		C
Platoon 3	X	W	W	A	A	C	A	A	A		C

Figure 23. Sample Company Guard Chart

Providing base communications for a company, whether in a fixed, OTM or dismounted environment, to meet current information requirements, the employment of multiple radio systems (in both manpack and vehicle configuration) to operate tactical radio channels is required. The PRC family of radios provide capabilities such as Ultra-High Frequency (UHF) channels for LOS communication, Very High Frequency (VHF) channels for within approximately five miles of the company, High Frequency (HF) channels for BLOS communication and Super High Frequency (SHF) for SATCOM channels. The channels provide the company with the base amount of architecture required for minimal services (voice and data) for C2.

As time and requirements have shifted in the data saturated environment in CONUS, it is logical to be able to provide these services to the tactical edge. Currently, HF channels provide a negligible amount of data capability to the company and do not satisfy the requirements for exchange of DISN services such as SIPRNet and NIPRNet. Currently, the only way for the company to obtain these services are in a fixed position. They are required to operate robust data architectures which require a significantly increased amount of data exchange with either the controlling battalion or from a Standardized Tactical Entry Point (STEP) site. Since these services must be obtained from units or sites at a great distance, usually BLOS or over-the-horizon, the requirement for more robust systems, temporarily loaned equipment such as a Support Wide Area Network (SWAN), MRC-145, WPPL or VSAT must be utilized. Table 4 presents the resident equipment for a Company based on their assigned equipment and equipment relinquished from higher echelon commands for basic C2 and reporting requirements from higher echelon commands.

Table 4. Current Equipment and Capability Matrix

Radio/System	Frequency	Distance	Capability/ (Data-Voice)	Data Speed	Resident/ Loaned	Operators	Configuration (FX,OTM,DIS)
PRC-117F	V/U/SAT	≤ 40km/ LOS/Indf	Both	≤ 64kbps	Resident	Yes	All
PRC-117G	V/U/SAT	≤ 40km/ LOS/Indf	Both	≤ 5mbps	Resident	Yes	All
PRC-148	V/U/SAT	≤ 2km/ LOS/Indf	Both	≤ 16kbps	Resident	Yes	OTM/DIS
PRC-150	HF/VHF	Indf/ ≤10mls	Both	≤ 9.6kbps	Resident	Yes	All
PRC-152	V/U/SAT	≤10mls/ LOS/Indf	Both	≤ 56kbps	Resident	Yes	All
PRC-153	UHF	1–5 mls	Voice Only	N/A	Resident	Yes	All
SWAN	SHF	Indf	Data	≤ 2.5mbps	Loaned	No	FX
WPPL	SHF	≤50mls	Data	≤ 50mbps	Loaned	No	FX
VSAT	SHF	Indf	Data	≤ 10mbps	Loaned	No	FX
MRC-142	UHF	≤ 35 mls	Both	≤16.64mb ps	Loaned	No	FX
MRC-145	V/U/SAT	≤ 40km/ LOS/Indf	Both	≤ 5mbps	Resident	Yes	FX/OTM
MRC-148	HF/VHF	Indf/ ≤10mls	Both	≤ 19.2kbps	Resident	Yes	FX/OTM
VRC-110	V/U/SAT	≤10mls/ LOS/Indf	Both	≤ 56kbps	Resident	Yes	FX/OTM
VRC-111	V/U/SAT	≤ 2km/ LOS/Indf	Both	≤ 16kbps	Resident	Yes	FX/OTM
VRC-112	V/U/SAT	≤10mls/ LOS/Indf	Both	≤ 56kbps	Resident	Yes	FX/OTM
VRC-113	V/U/SAT	≤ 2km/ LOS/Indf	Both	≤ 16kbps	Resident	Yes	FX/OTM
VRC-114	V/U/SAT	≤ 40km/ LOS/Indf	Both	≤ 5mbps	Resident	Yes	FX/OTM

As can be seen from Table 4, all high bandwidth assets require being loaned from higher echelon commands. As well, Marines required to operate the gear must also be attached since resident MOSs are not present at the subordinate commands such as a Company and below. The need for increased bandwidth and flexibility on the battlefield arises from the concentration of effort found in garrison training environments and its use of commercial and governmental networks. As stated previously, the Marine Corps has developed and adopted various systems and applications to assist commanders in improving the decision-making and information dissemination cycle but falter in making those applications and resources available to Marines on the tactical edge.

B. FUTURE COMPANY, PLATOON AND SQUAD REQUIREMENTS

Future operating environments in concert with new technologies will be the standard where the D2D cycle is reduced to minimums and not restricted by the availability of applications and systems used to train. Utilizing PaaS to make GOTS SoS highly available via SaaS to provide availability of systems and applications is the logical approach and will enhance the effectiveness of the warfighter on the tactical edge. The PaaS approach will be leveraged by current and future SoS and enable the warfighter to have complete autonomy from the Company and Battalion allowing for near real time updates and inputs to critical systems used to enhance BFSA. Table 5 contains systems and applications tactical edge personnel train with in garrison but do not utilize in combat environments leading to a lack of BFSA. The list is not exhaustive but contains more of the well-known applications and systems in use.

Table 5. Current Garrison and Combat Systems and Applications

System/Application	Availability (Garr/Cmbt)	Configuration (FX,OTM,DIS)	PaaS Dependent	Company / Below	Battalion / Above
TCO	Both	FX	Yes	No	Yes
CLC2S	Both	FX	Yes	No	Yes
GCSS-MC	Both	FX	Yes	No	Yes
SPEED	Both	FX	Yes	No	Yes
AFATDS	Both	FX	Yes	No	Yes
BUCS	Both	OTM, DIS	No	Yes	No
DCGS-MC	Both	FX	Yes	No	Yes
SIP (SIPRNet)	Both	FX	Yes	Yes	No
SBUIP (NIPRNet)	Both	FX	Yes	Yes	No
CENTRIXS	Cmbt	FX	Yes	Yes	No
JBC-P	Both	FX	Yes	No	Yes
BFT	Both	FX, OTM	No	Yes	No
FMV	Both	FX	Yes	No	Yes

As seen in Table 5, there is a capability gap between the systems and applications available to Company and below personnel while in a deployed environment and being in a fixed location compared to the availability while OTM or dismounted. The availability of systems and applications PaaS provides will provide key resources required for proper operation and functionality. It will also provide a platform to serve Marines on the tactical edge via a networked backbone enabling enhanced BFSA and decision making capabilities.

C. THE FUTURE WITH PAAS AT THE TACTICAL EDGE

The warfighter of today and tomorrow demands cutting edge technology intricately laced through the fabric of legacy and cloud-based SoS. Providing tactical edge personnel with PaaS will provide the capability to host and administer the previously listed applications presenting them to PaaS as SaaS widgets. The back-end of legacy SoS requires integration with PaaS/DaaS. The ability to advance legacy SoS by creating cloud based SoS to deploy newly developed applications should be available on PaaS. Having this capability by itself does not mean an enhancement of services by default. A detailed and complete set of requirements must be defined to better equip tactical edge users with the most relevant and pertinent products and services while reducing the overburden of multiple applications and systems providing alike information. The desired endstate is a warfighter equipped with valuable relevant information that promote enhanced C2 while reducing the D2D cycle.

1. Application and Program, System and Device Requirements

When all of the dust settles on the enormous amount of duplicate applications and programs, there is a basic level of tactical edge user requirements. The basic need is to have the best possible situation awareness and C2 in one place to decrease the D2D cycle for the person in charge. Enabling PaaS in a fixed, OTM or dismounted configuration is the base requirement for being able to host required components. Being able to administer and host all required applications and programs from a platform capable of operating in all three operational configurations is a must but has to be combined with other assets to serve the need. Below is a list, separated into three categories, of the base requirements.

- Applications and Programs
    - C2 Planning and Operations: graphical depiction of a SOP incorporating programs such as TCO, FMV, BFT and JBC-P
    - Logistics: mobile version of CLC2S or GCSS-MC with SOP with capability to request resources
    - ISR: ability to view PLI of friendly and enemy units (BFT), FMV of UAV or other technologies aggregated
    - C2 Support: capability to request CFF utilizing AFATDS and BUCs, CAS, MedEvac and Ground Support (food, water, ammunition and medical supplies)
- Cloudlet Infrastructure
    - PaaS: provide a platform to create and host multiple applications supporting all range of operations and providing a SOP for all levels of command to obtain key data views enhancing decision making and reducing the D2D cycle. PaaS must be capable to support write-back as well as on-demand requests. SOP is expected to provide the necessary transparency to monitor provisioning of on-demand requests across command organizational hierarchy. Internal auditing provides an impetus for superior operational capabilities.
- Networks
    - SIP (formerly SIPRNet): provide the capability to create, capture, manipulate, disseminate and collaborate on a secure platform.
    - SBUIP (formerly NIPRNet): provide the capability to create, capture, manipulate, disseminate and collaborate on an unclassified platform.
- Mobile Computing Device
    - Mobile capable asset with the ability of visual presentation of multiple facets of the battlefield. The device must be large enough to legibly read and manipulate menus in combat attire. The device must be capable to support write-back functionality and retail full usability when in a DIL environment. The device must also have enough random access memory (RAM) to perform multiple operations simultaneously.

The preceding requirements are a baseline set to guide the creation and foundation to equip the tactical edge user with the tools necessary to enhance and assist in shortening the D2D cycle. The list of requirements is not all encompassing and represents the minimum to satisfy operating levels dependent on the complexity or detailed planning and preparation which took place prior to and during operations. Providing integration or incorporation with applications will provide the commonality the warfighter needs to maintain their efficiency and familiarity with current SoS. The ability and capability to request or direct actions on enemy targets is another key feature. Current applications provide the warfighter with the capability to direct actions on enemy targets or positions. By providing easily accessible icons or links for requesting theses services, it will decrease the time on target by automating the process. Preconfigured information can be stored on the mobile computing device during mission planning; therefore decreasing the time it takes to request all services. Another one of the services it can speed up is medical evacuations. Having the icon or link at your finger tip, with current PLI data automatically inserted and preconfigured data already in place, medical evacuations will be more streamlined reducing the amount of delay injured personnel must have to wait for life critical services. To make the most of the applications or programs listed, careful consideration must be taken to ensure there is as little redundancy as possible and all of the contents are capable of being administered on a handheld device.

Handheld computing devices are common-place in the world today and most people are familiar with device usage. A mobile capable asset such as a tablet, smartphone or other hand-held computing device has to be incorporated into the PaaS solution to enhance the capabilities provided by it. The computing device must have the capability to interface, either wirelessly or tethered cable, with an available connection to the PaaS cloudlet or be able to operate from internal memory. On-device storage is one of two critical factors that must be taken into consideration. Storage on the device would permit it to maintain operational ability in a DIL environment. Security is the other critical issue which needs to be taken into consideration. Communications between the mobile device and PaaS cloudlet must be continuously monitored to ensure operational security is maintained. Procedures must be put in place to ensure the security of both wireless and wired communications as well as lost or misplaced mobile computing devices.

PaaS at the tactical edge will provide warfighters the capabilities they require to make timely and accurate decisions. Reducing the D2D cycle and providing key details on BFSA, military personnel will have the tools necessary to lead them into future combat situations. The possibilities for implementations and incorporation into the operating forces are almost endless and it will require tremendous thought, preparation, development and implementation to ensure maximum capabilities are deployable.

IV. EQUIPMENT DESIGN

In order to provide network services to the tactical edge, a mobile device connection to the cloud via the cloudlet in conjunction with adaptable edge user warfighting applications is needed as previously described in Chapter II. As shown in Figure 24, connecting the mobile user with the enterprise end-to-end data architecture is essential to improved decision-making, BFSA, and C2 based upon all available resources.

Figure 24. Enterprise Information Environment (from Takai, 2012)

The Naval Research Advisory Committee (2012, p. 24) projected that in the U.S. alone approximately 260 million smart phones will be in use by the upcoming year. As a result, the average recruit will arrive to basic training with their own mobile device; therefore, decreasing the learning curve of military variants with the same look and feel (Naval Research Advisory Committee, 2012, p. 24).

A. DESIGN SPECIFICATIONS

Previous Raytheon development of an integrated C2 solution (One Force Tactical Communication System [OFTCS]) consisting of a "client application, OFT server, and hybrid network" (tactical/commercial) serve as a viable model (Young & Ishii, 2012, p. 1). The OFTCS architecture is designed to provide two levels of communications on both android based mobile devices; as well as, apple based mobile devices:

- Redundant, OTM warfighter communications (Young & Ishii, 2012)
- High-speed, OTH, deployable network infrastructure (Young & Ishii, 2012)

The ability to deliver the above listed capabilities would satisfy the C2 requirements of the current and future warfighter at the tactical edge. As depicted in Figure 25 and Figure 26, Young and Ishii (2012) determined that SOP can be achieved using a well-connected mobile device.

Figure 25. Mobile Device BFSA (from Young & Ishii, 2012)

Figure 26. Mobile Device Video Sharing (from Young & Ishii, 2012)

Previous thesis research conducted by Liguori et al. (2013) focused on the need for a secure mobile device and the current available options to achieve this IAW DOD policies and directives. Therefore, the prototype design will ignore the security requirements and will leverage previous research as to avoid duplicative efforts.

B. PROTOTYPE

The graphical user interface (GUI) of current mobile devices allows the user to interface with applications without having to use the command line interface. As such, this has become the standard by which mobile device and hosted application interact; thus will be the foundational design leveraged for the prototype. All opportunities to autofill dropdown menus will be auto-populated from the information store on the unit's database. Friendly and enemy position locations are generated from a selective availability anti-spoofing module (SAASM) based global position system (GPS) location receiver either embedded or attached to the mobile device. As of 1 October 2006, SAASM compliant precise positioning system devices are required in all newly fielded DOD GPS devices (Holm, 2006). The below listed figures depict the prototype mobile device:

- Figure 27 shows the startup screen and the list of warfighting applications: call for fire, close air support, full motion video, medical evacuation (MEDEVAC), logistic resupply, and situational report.
- Figure 28 shows the call for fire home screen
- Figure 29 shows the call for fire mobile application with drop down menu
- Figure 30 shows the adjust fire mobile application with drop down menu
- Figure 31 shows the close air support home screen
- Figure 32 shows the close air support 9 line brief
- Figure 33 shows the close air support 6 line brief
- Figure 34 shows the full motion video home screen
- Figure 35 shows the full motion video feed and map overlay
- Figure 36 shows the color full motion video feed
- Figure 37 shows the logistics support home screen
- Figure 38 shows the air support request application
- Figure 39 shows the ground support request application
- Figure 40 shows the MEDEVAC home screen
- Figure 41 shows the air MEDEVAC request application
- Figure 42 shows the ground MEDEVAC request application
- Figure 43 shows the situational update report home screen
- Figure 44 shows the situational update report application

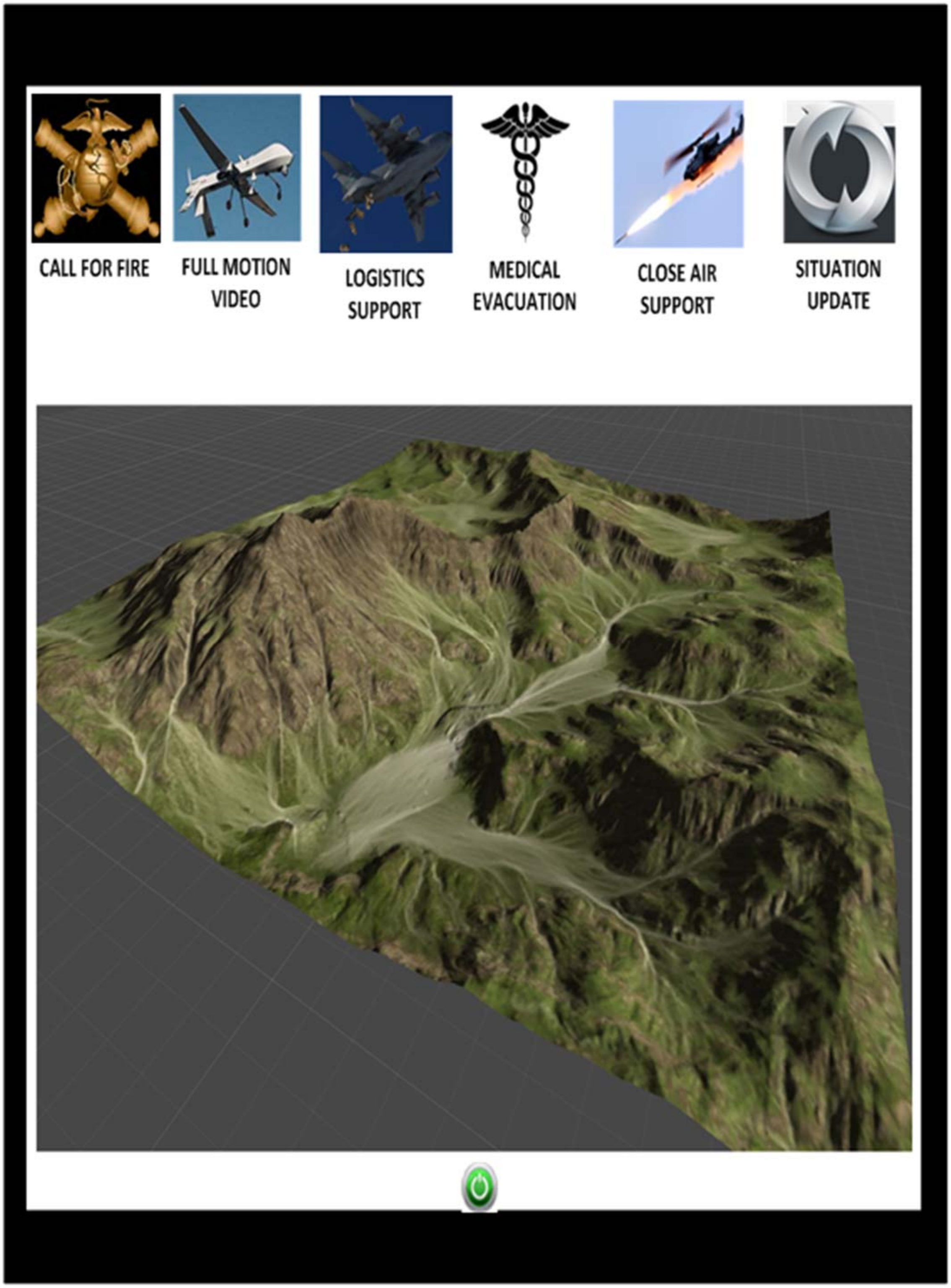


Figure 27. Mobile Device Startup Screen

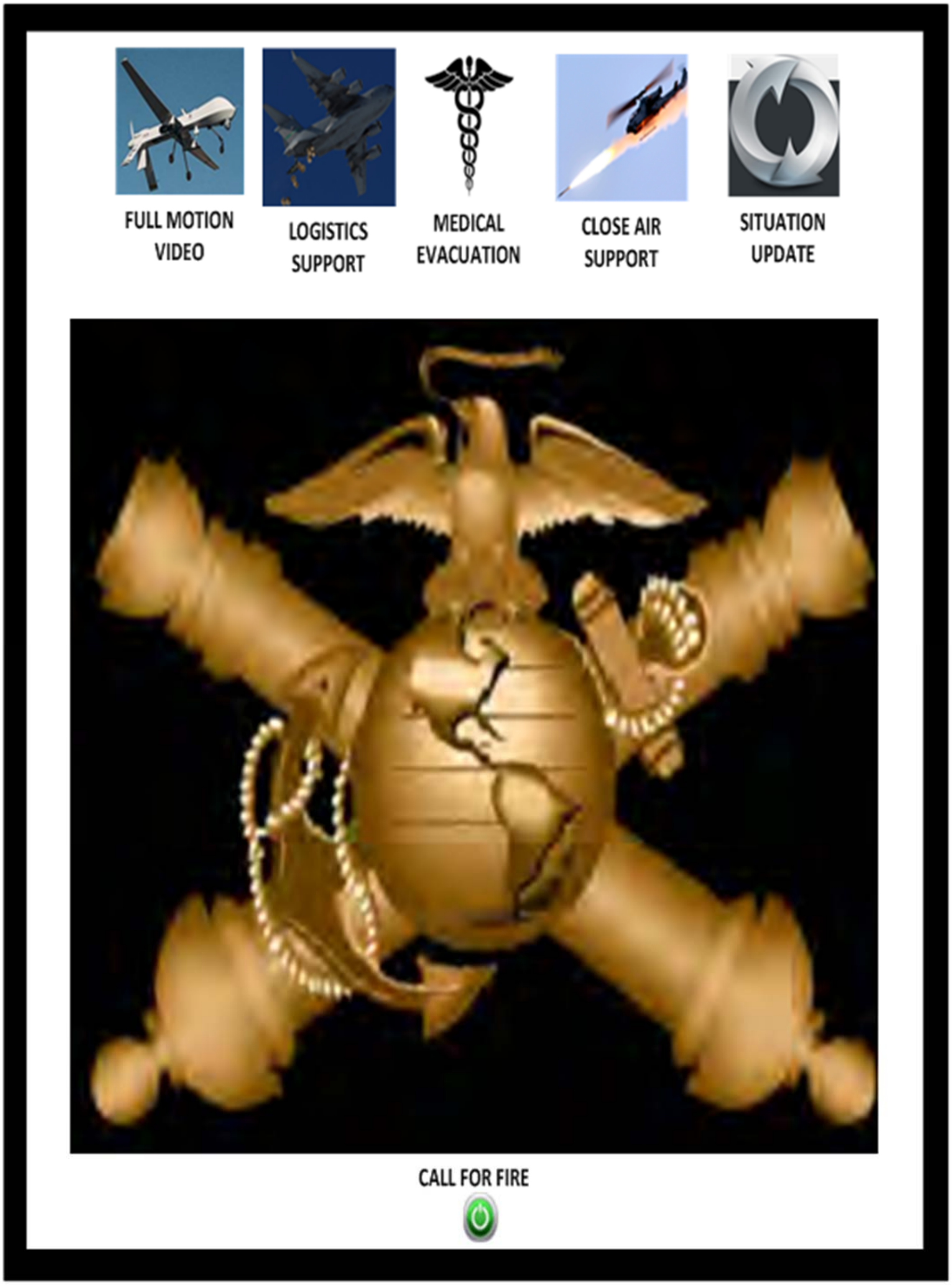


Figure 28. Call For Fire Home Screen (from Oregon, 2011)

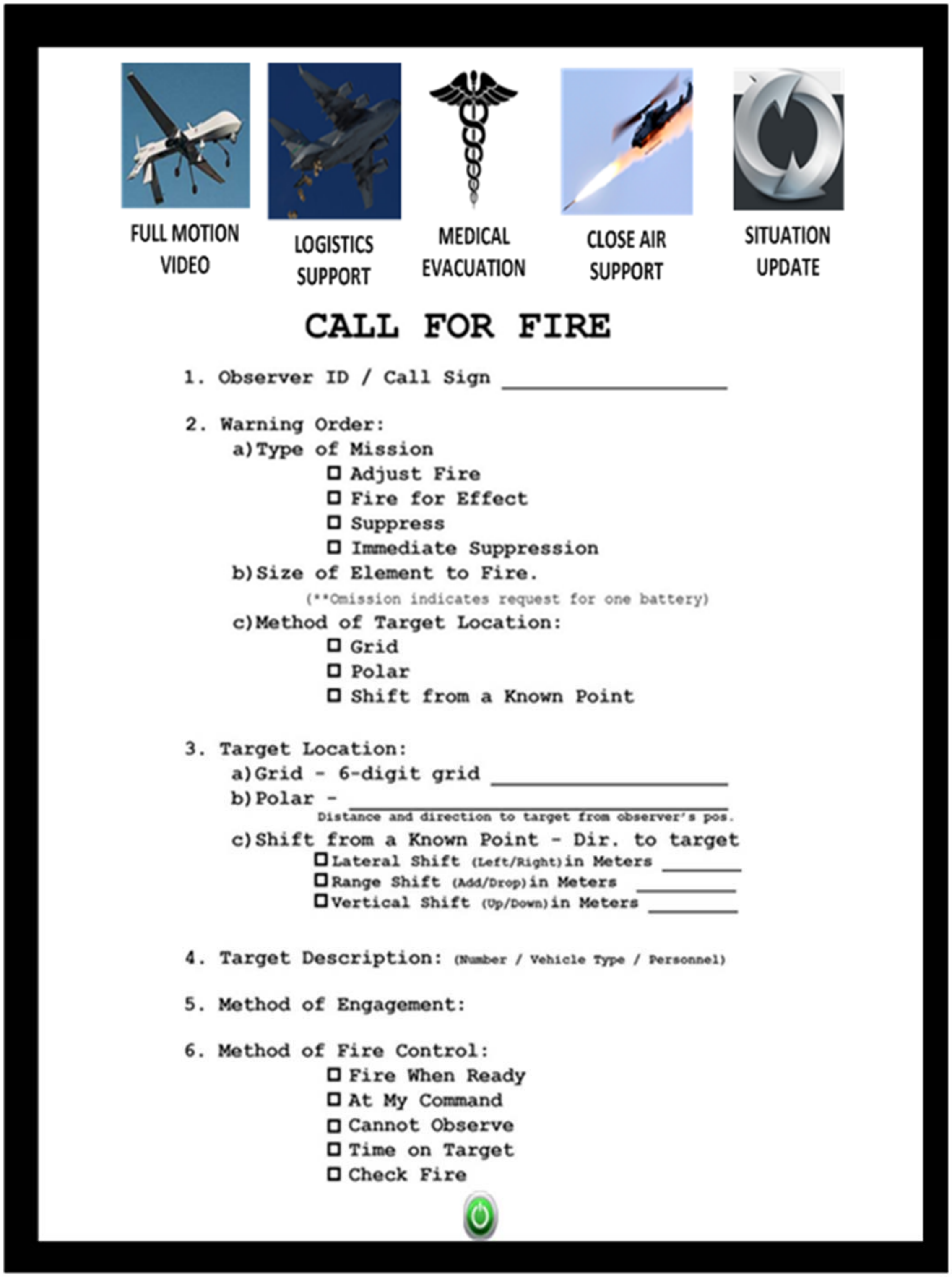
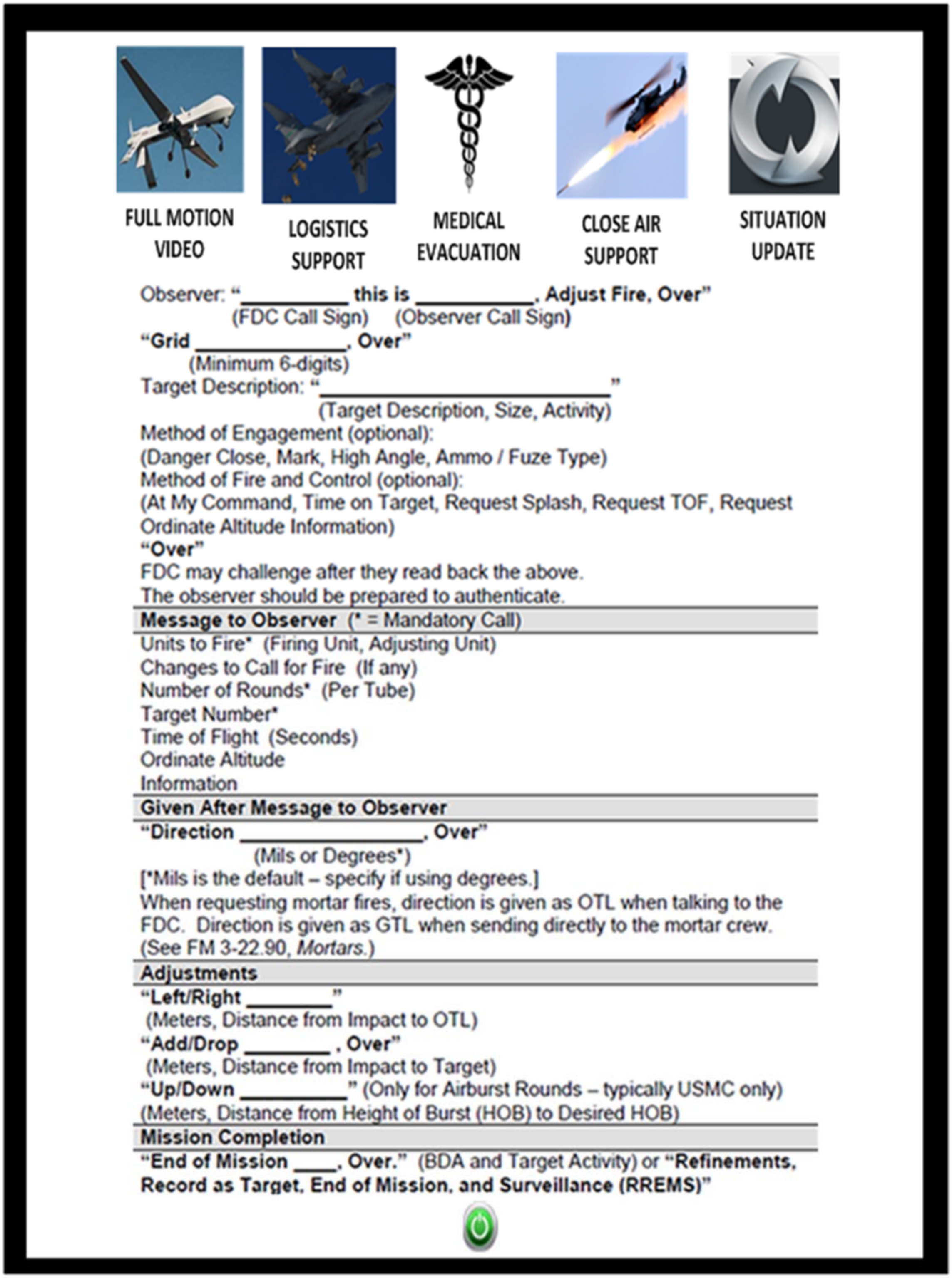


Figure 29. Call For Fire Mobile Application (from RedWireDesigns, n.d.)



Observer: "__________ **this is __________, Adjust Fire, Over"**
(FDC Call Sign) (Observer Call Sign)
"Grid ______________, Over"
(Minimum 6-digits)
Target Description: "____________________________"
(Target Description, Size, Activity)
Method of Engagement (optional):
(Danger Close, Mark, High Angle, Ammo / Fuze Type)
Method of Fire and Control (optional):
(At My Command, Time on Target, Request Splash, Request TOF, Request Ordinate Altitude Information)
"Over"
FDC may challenge after they read back the above.
The observer should be prepared to authenticate.

Message to Observer (* = Mandatory Call)

Units to Fire* (Firing Unit, Adjusting Unit)
Changes to Call for Fire (If any)
Number of Rounds* (Per Tube)
Target Number*
Time of Flight (Seconds)
Ordinate Altitude Information

Given After Message to Observer

"Direction ________________, Over"
(Mils or Degrees*)
[*Mils is the default – specify if using degrees.]
When requesting mortar fires, direction is given as OTL when talking to the FDC. Direction is given as GTL when sending directly to the mortar crew. (See FM 3-22.90, *Mortars*.)

Adjustments

"Left/Right ________"
(Meters, Distance from Impact to OTL)
"Add/Drop ________, Over"
(Meters, Distance from Impact to Target)
"Up/Down __________" (Only for Airburst Rounds – typically USMC only)
(Meters, Distance from Height of Burst (HOB) to Desired HOB)

Mission Completion

"End of Mission ____, Over." (BDA and Target Activity) or **"Refinements, Record as Target, End of Mission, and Surveillance (RREMS)"**

Figure 30. Adjust Fire Mobile Application (from J-FIRE, 2007)

Figure 31. Close Air Support Home Screen

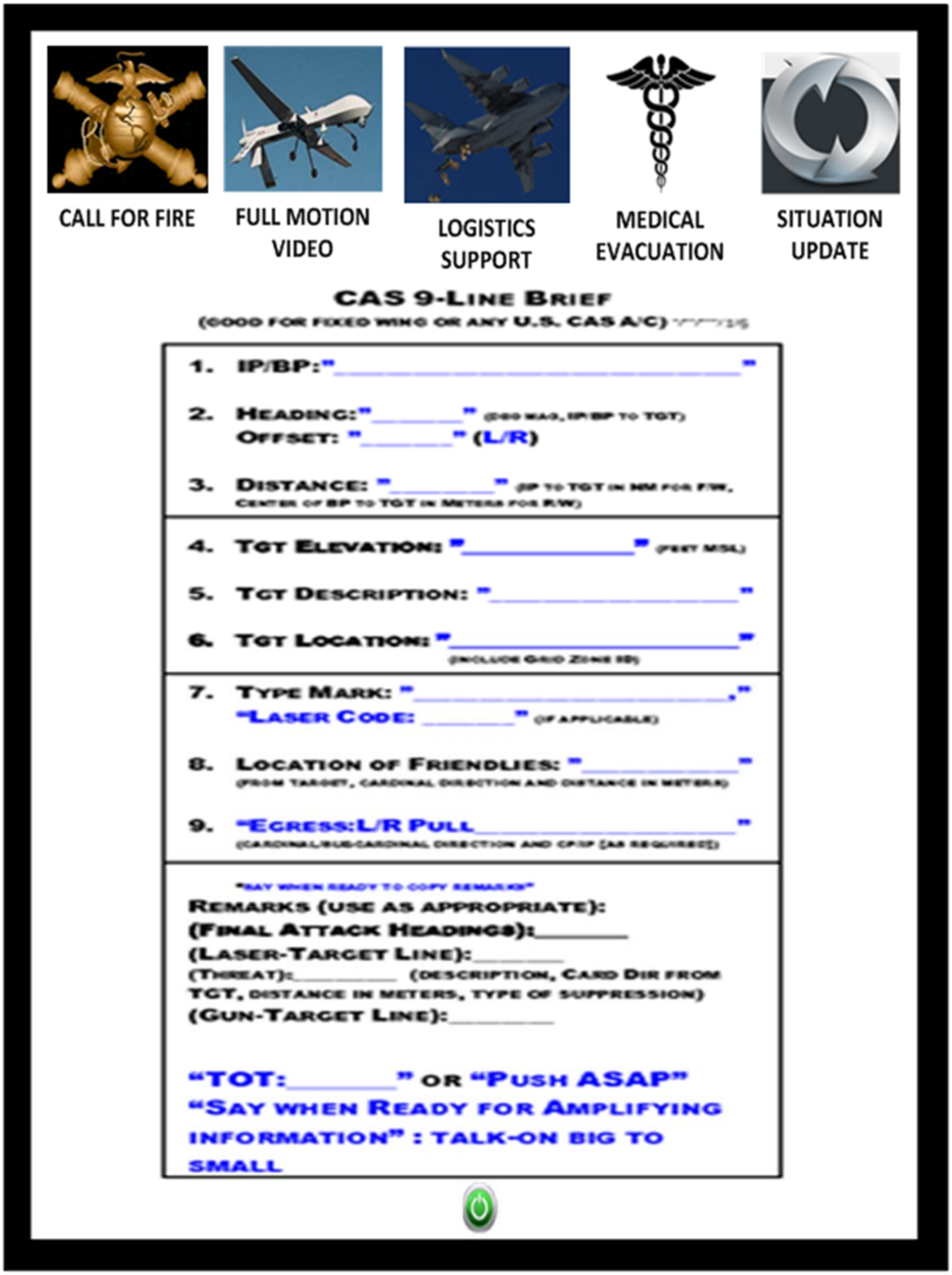


Figure 32. Close Air Support 9-Line (from PHOTOINDEX.W.PW, 2008)

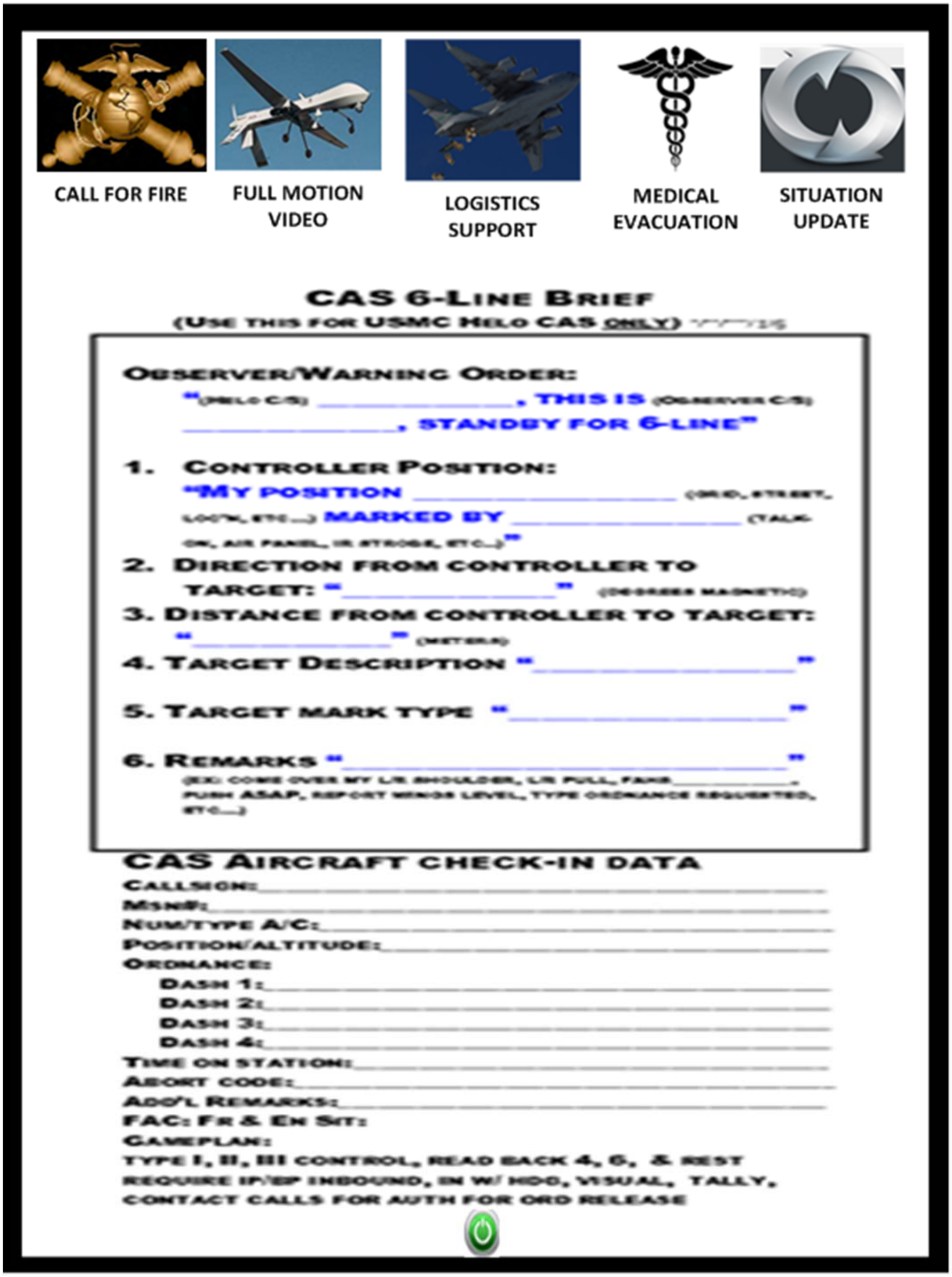


Figure 33. Close Air Support 6-Line Brief (from PHOTOINDEX.W.PW, 2008)

Figure 34. Full Motion Video Home Screen

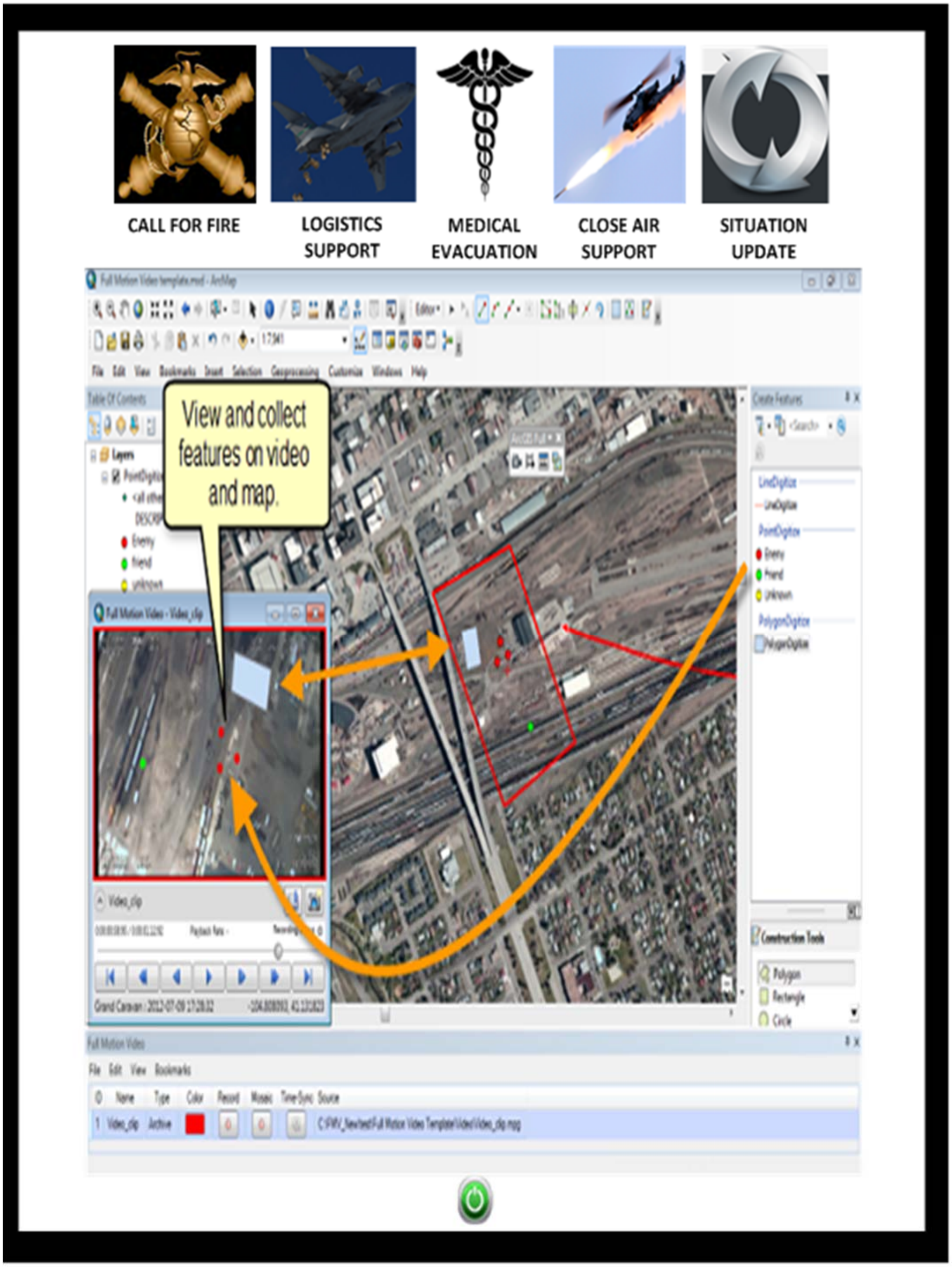


Figure 35. Full Motion Video and Map Overlay

Figure 36. Color Full Motion Video Feed

Figure 37. Logistics Support Home Screen

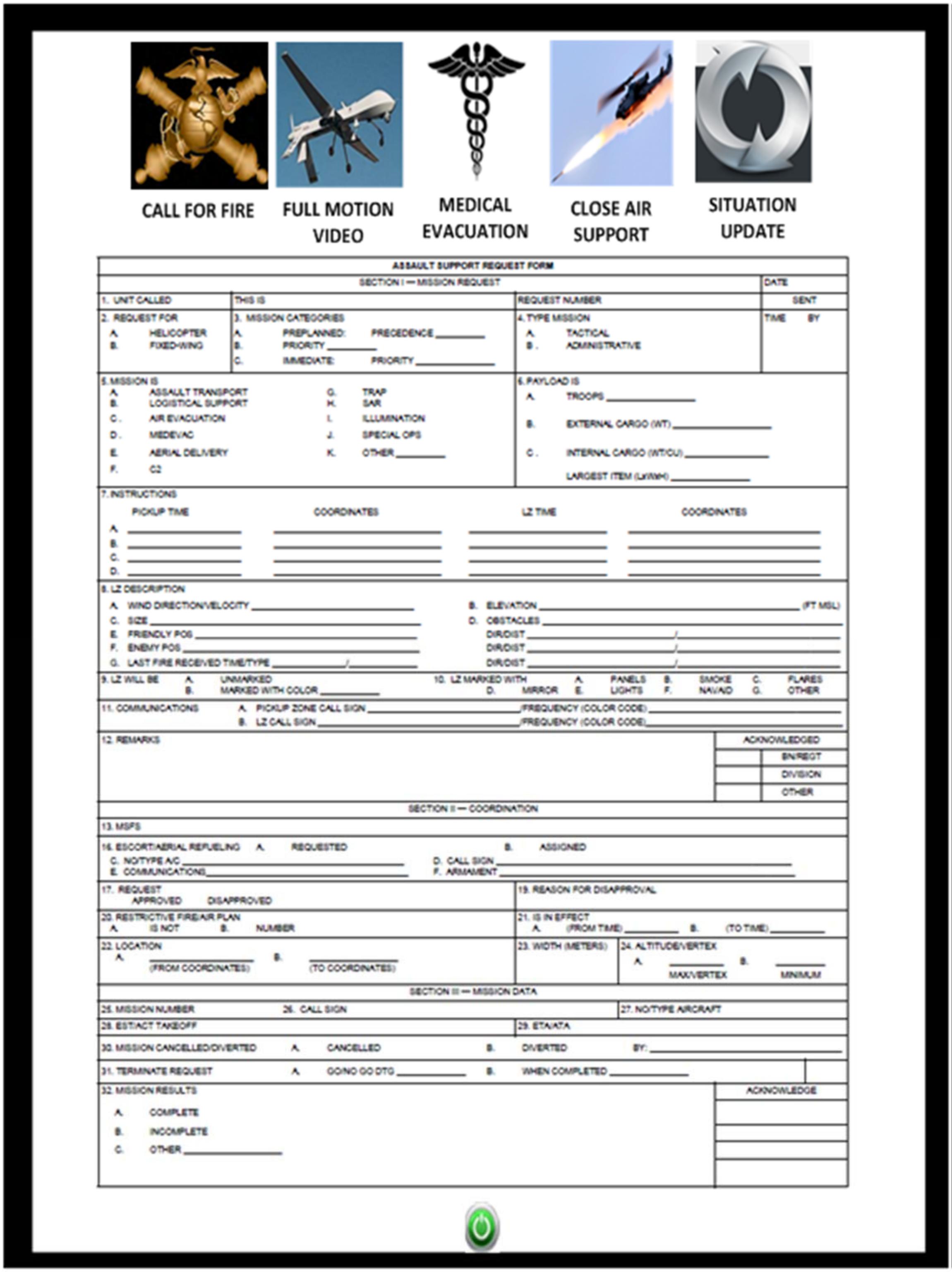
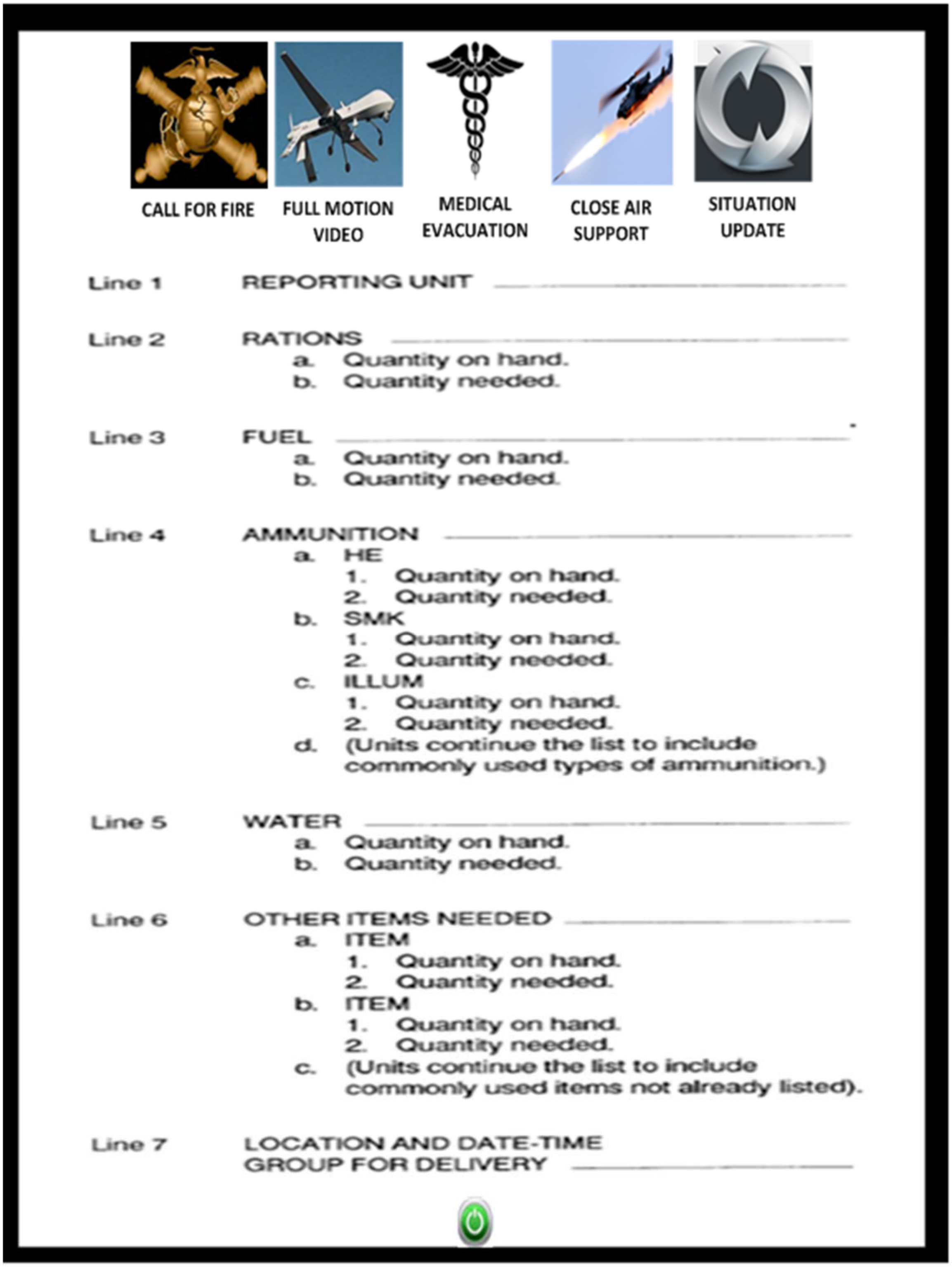


Figure 38. Air Support Request (from U.S. Marine Corps, 2004)



CALL FOR FIRE
FULL MOTION VIDEO
MEDICAL EVACUATION
CLOSE AIR SUPPORT
SITUATION UPDATE

Line 1 REPORTING UNIT ______________________

Line 2 RATIONS ______________________
a. Quantity on hand.
b. Quantity needed.

Line 3 FUEL ______________________
a. Quantity on hand.
b. Quantity needed.

Line 4 AMMUNITION ______________________
a. HE
1. Quantity on hand.
2. Quantity needed.
b. SMK
1. Quantity on hand.
2. Quantity needed.
c. ILLUM
1. Quantity on hand.
2. Quantity needed.
d. (Units continue the list to include commonly used types of ammunition.)

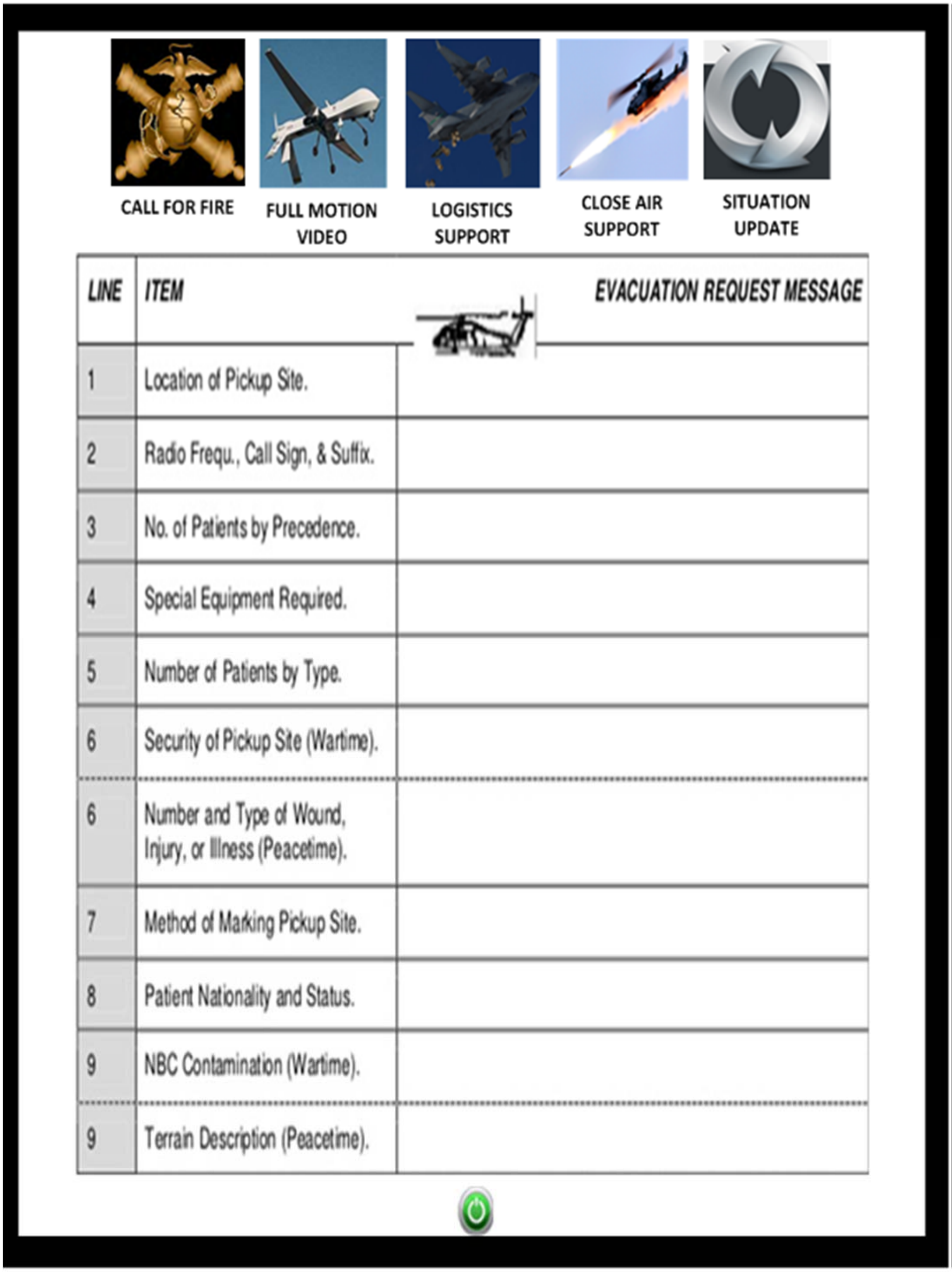
Line 5 WATER ______________________
a. Quantity on hand.
b. Quantity needed.

Line 6 OTHER ITEMS NEEDED ______________________
a. ITEM
1. Quantity on hand.
2. Quantity needed.
b. ITEM
1. Quantity on hand.
2. Quantity needed.
c. (Units continue the list to include commonly used items not already listed).

Line 7 LOCATION AND DATE-TIME GROUP FOR DELIVERY ______________________

Figure 39. Ground Support Request (from Department of the Army, 1993)

Figure 40. MEDEVAC Home Screen



LINE	ITEM	EVACUATION REQUEST MESSAGE
1	Location of Pickup Site.	
2	Radio Frequ., Call Sign, & Suffix.	
3	No. of Patients by Precedence.	
4	Special Equipment Required.	
5	Number of Patients by Type.	
6	Security of Pickup Site (Wartime).	
6	Number and Type of Wound, Injury, or Illness (Peacetime).	
7	Method of Marking Pickup Site.	
8	Patient Nationality and Status.	
9	NBC Contamination (Wartime).	
9	Terrain Description (Peacetime).	

Figure 41. Air MEDEVAC Request (from Department of the Army, 2000)

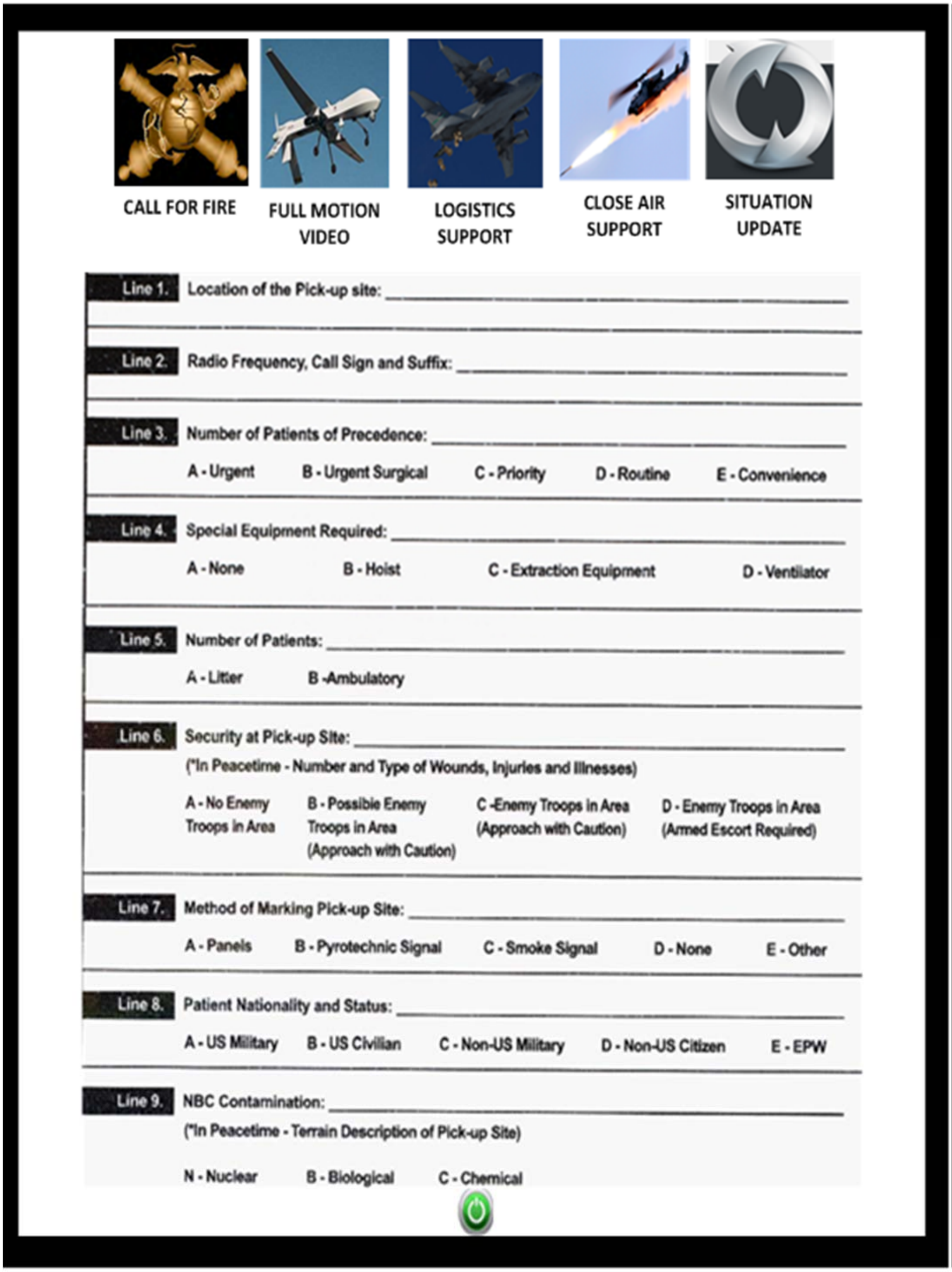


Figure 42. Ground MEDEVAC Request (from Department of the Army, 2000)

Figure 43. Situational Update Report Home Screen

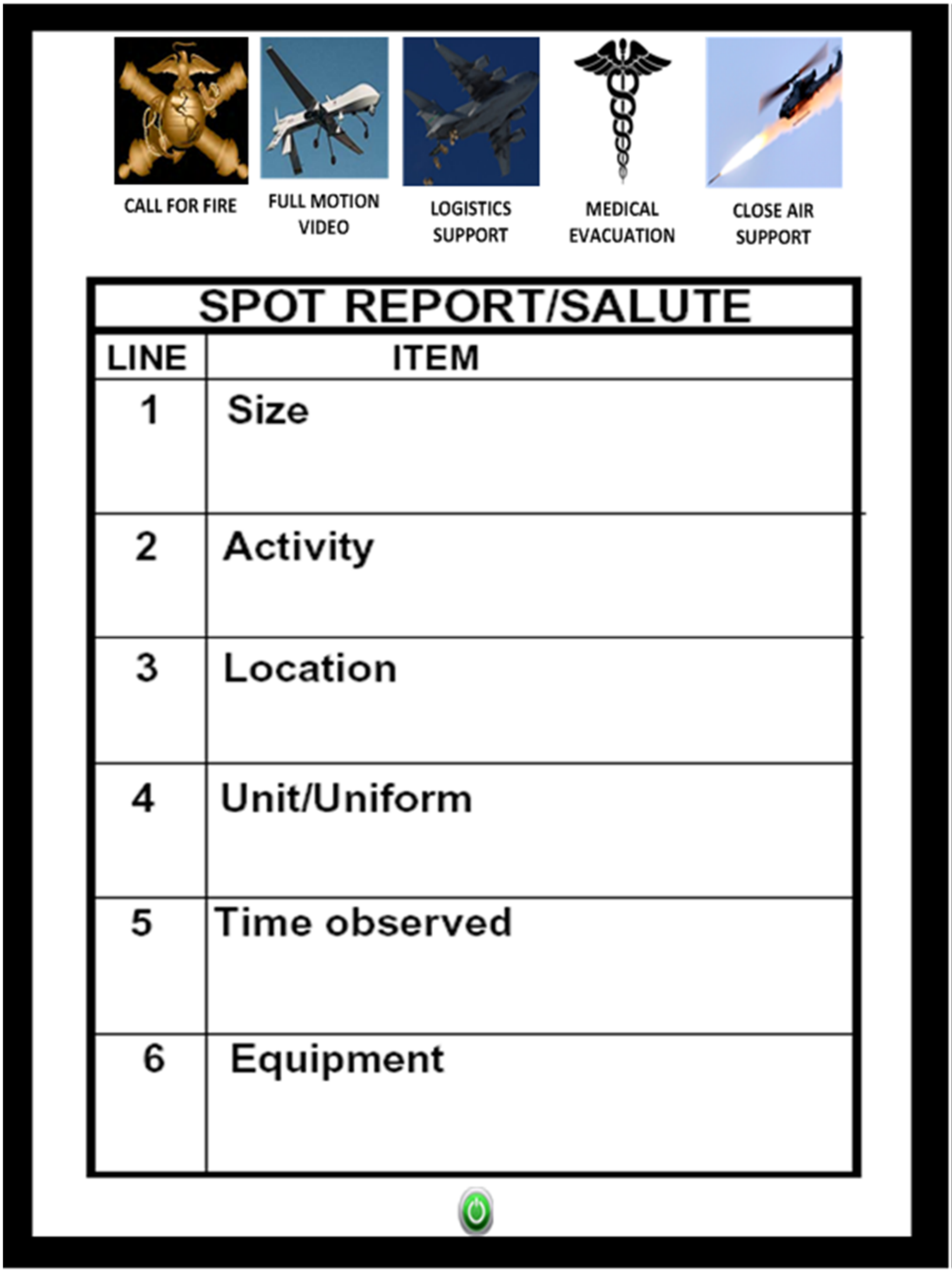


Figure 44. Enemy Reconnaissance Application (from Department of the Army, 2006)

With the aforementioned designed prototype available, an edge unit equipped with a mobile device is empowered with access to the critical C2ISR capabilities needed to decrease the D2D cycle. The intuitive nature of the graphical display allows for navigation between applications that may be employed during a troops-in-contact (TIC) situation as demonstrated in the following scenario. A squad conducted a presence patrol and used their mobile device to upload the route and checkpoints that would be used to navigate 1000 meters away from their FOB. Before departure, they were informed they would have overhead imagery assets (satellites and unmanned aerial vehicles) assigned due to the growing unrest in the area. Once outside of the FOB, they noticed a group of males with weapons approximately 200 meters away. The squad leader was able to leverage the available overhead imagery and viewed the males' activities on the mobile device via the FMV application. The squad leader reported that the males were armed with small arms weapons to the company leadership through the SITREP update application. The squad was instructed to continue the patrol and to monitor the males to see if there is any change in behavior.

As the squad gained ground on the stationary males, they observed several males take a defensive posture and obtain cover behind vehicles and buildings. Shots were fired from the males and the squad notified the company leadership that they were involved in a TIC. A member of the squad was severely injured due to the overwhelming volumes of fire from the direction of an abandoned one-story building. The squad relocated the wounded personnel to a covered position and immediately performed life-saving treatment. After they opened and used the MEDEVAC application to request an air evacuation, they switched over to the SITREP update application in order to notify the company headquarters. Midway through completing the update, the squad leader received an update in the MEDEVAC application that indicated the helicopter was 30 minutes out from their location. The squad leader switched back to the SITREP update application and picked up right where he left off at the last data entry point. The natural and man-made objects obstructed the view of the squad; however, they were able to observe the assailants with the use of overhead aerial imagery. The squad leader opened the CAS application and used the 10-digit grid coordinates provided by the overhead aerial imagery to positively identify the enemy combatants' location. The CAS engagement effectively neutralized the targets and rendered them incapable of continuing to fight, which was monitored by the squad via the FMV application. Updates were sent to both the company headquarters and the inbound helicopter via the SITREP update application/MEDEVAC application, respectively. Although fictitious, the potential to encounter a complex scenario of this magnitude is a realistic possibility for units operating at the tactical edge.

The prototype design by the researchers demonstrated the usefulness, in the aforementioned scenario, of combining a tactical cloudlet/PaaS architecture that host warfighting and sensor applications accessible via a mobile device. The ability to have an agile system that is responsive to the fluid nature of combat and is able to traverse many applications without degrading the warfighting capability of the end-user is critical. The design should enhance the user's ability to succinctly perform multidimensional single data entry and query with minimal duplicative inputs as much as possible. Automation would effectively enhance the edge users D2D cycle in a time constrained environment by eliminating unnecessary manual entry and query requirements. Since the connected applications share information as a composite request, then data entry and query requests are submitted in data views with write-back.

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V. OPERATING IN DENIED DIL (D-DIL) ENVIRONMENT

The U.S. military must keep pace with and exploit the capabilities presented by the evolution of technology. As such, the desire to capitalize on the advancements made in the commercial sector is tapered by the requirement to negate vulnerabilities to the Department of Defense Information Network (DODIN). The next generation of service members grew up in the information age and they are accustomed to owning and operating mobile network computing devices with persistent connection to the Internet. They have an expectation that the cloud is not only available at all times but that it will remain available without failure. The desired end state is to make the DODIN synonymous with "good end-to-end network quality" with negligible cloud or loss of network connectivity (Satyanarayanan et al., 2013, p. 40). Unlike the commercial sector, the DODIN is deployed forward in hostile D-DIL environments in support of contingency operations; therefore, methods of employment in response to enemy threats require unique considerations. A capability is needed to minimize the effects of the enemy's successful disconnection of the edge user to the cloud. In accordance with our current equipment capabilities, a severing of this connection would significantly degrade their ability to conduct C2 due to loss of the C4ISR capability. The researchers advocate a mobile device design using a tactical cloudlet/PaaS networked architecture as shown in Figure 45:

> A surrogate or proxy of the real cloud, located as the middle tier of a three-tier hierarchy: mobile device, cloudlet, and cloud. It is completely transparent under normal conditions, giving mobile users the illusion that they are directly interacting with the cloud. Under failure conditions, the cloudlet masks the absence of the cloud by performing its essential services. (Satyanarayanan et al., 2013, p. 40)

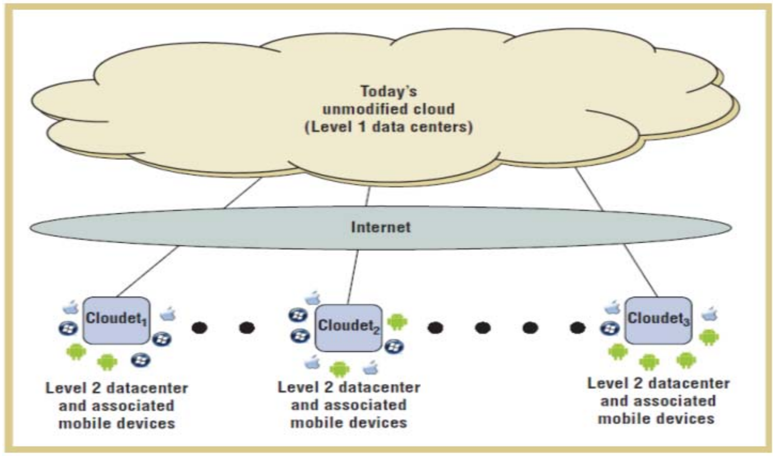

Figure 45. Two-level Cloud Computing Architecture,
(from Satyanarayanan et al., 2013, p. 44)

In support of the highly mobile user, the well-connected tactical cloudlet/PaaS architecture is designed to leverage the integrated schema of the data cube (dimension tables/fact tables) within the HHQ data mart that perform interactive manipulation of data as seen in Figure 46.

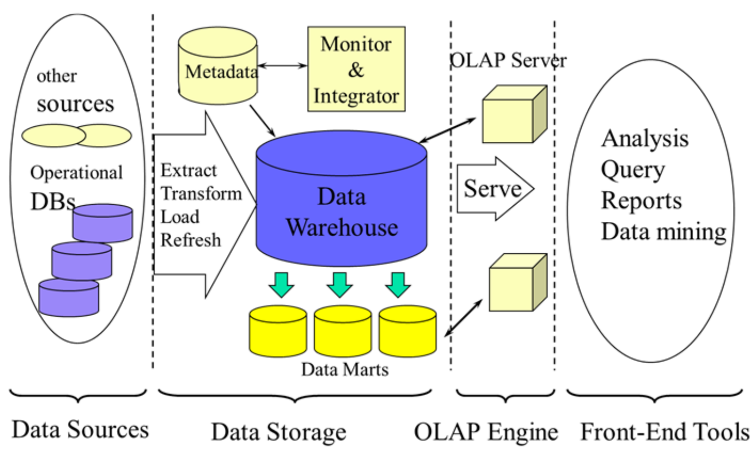

Figure 46. Data Warehouse: A Multi-Tiered Architecture
(from Slideshare.net, 2008)

The data cube is the method used by the data mart to accurately list stored data.

The base cuboid has the sources of raw data and when queried provides raw data for the production of consumable analysis-based decision-oriented information. Once complete, the finished information/data is

> ready for consumption and is delivered to the requestor as a summarization in the apex cuboid. (Pujari, 2001, pp. 15–17)

According to Reddy, Srinivasu, Rao, and Rikkula (2010, p. 2867), data in a data mart is described as: subject oriented; integrated; and time variant.

A. COMPUTERIZED DECISION SUPPORT SYSTEM

The decision-maker requires access to the summary data views for analysis and raw data views to update the transactions; however, having summary views with the summaries of raw views and derived summary of summaries is not allowing the decision-maker to update the transaction. With a need for the decision-maker to update the transactions, there should be raw views with transactional data. As such, all data marts (HHQ, adjacent, and subordinate) must support both summary and raw data views. This cycle that is comprised of the analysis of summary views followed by updating transactions depicts the decision-making loop that supports day-to-day operating activities. The computerized DSS goal is to keep the decision-maker connected to the aforementioned decision-making loop. As an edge user navigates across the screens displaying data views for all applications, computerized DSS provide SOP with transparent access to available resources at relevant tiers of command, evaluation of operational scenarios, and drilling down/rolling up to conduct analysis at appropriate cuboid. These navigation (drilling down and rolling up) capabilities allow for the movement "from higher level summary to lower level summary or detailed data" within the data views (Wang, 2008, p. 160).

Drill-down capability provides the decision-maker with the ability to critically analyze data, such as splitting the metadata on a given dimension according to the hierarchy (e.g., temporal, spatial, and organizational hierarchies) on the corresponding dimensions across the dimensions in a query (Weippl, Mangisengi, Essmayr, Lichtenberger, & Winiwarter, 2001, pp. 1–5). Commanders have to consider the hierarchies when developing mission orders and coordinating CS/CSS for subordinate units operating on the FOB; in non-FOB areas; or within the AOR as depicted in Figure 47.

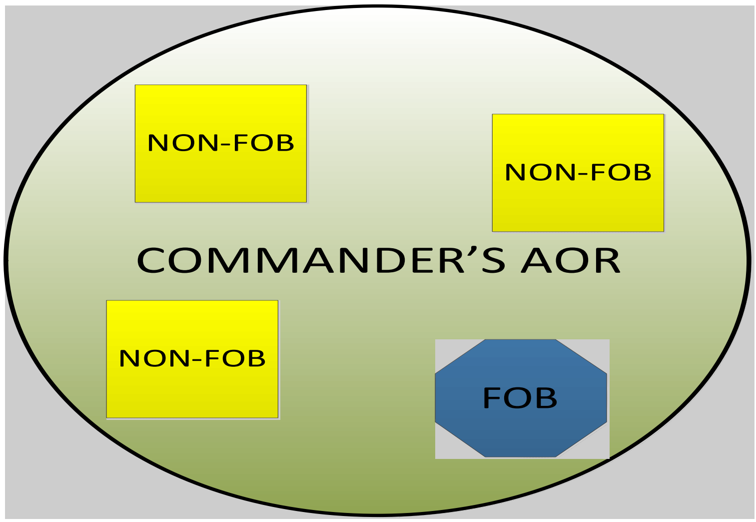

Figure 47. Commander's Spatial Drill Down Requirements

This requires the commander and subordinate decision-makers to have a well-connected mobile device, whose access to the data marts at their level of command deliver the information necessary to perform auto-population within enabled warfighting application fields. In addition to the intuitive ability to navigate across the organizational hierarchy, the commander requires the ability from the mobile device to drill down relative to units of time and space. The commander's dissemination of timelines to subordinate units must coincide with the commander's assigned overall campaign timeline from HHQ. These seemingly disparate functions are running in parallel from the perspective of the commander; thus, requiring the commander's ability to perform both drill down and rollup functions.

Also, the assignment of mission-type orders to subordinates is expressed through the temporal, spatial, and organizational hierarchy as depicted in Figure 48.

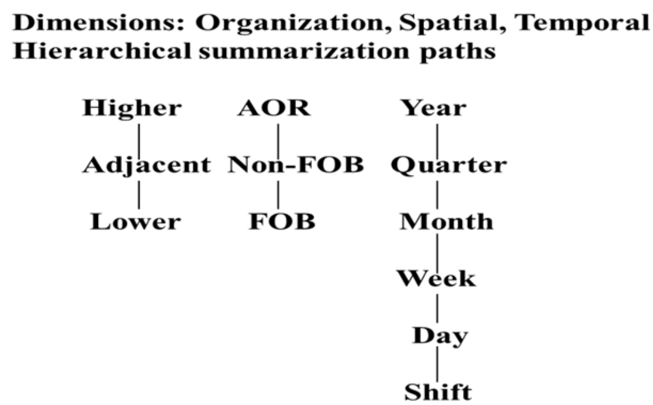

Figure 48. Hierarchical Dimensions

As previously stated the commander must be cognizant of time; however, now has to consider geographical location. HHQ task to perform the full spectrum of warfare (stability operations to full-scale combat) within an assigned AOR requires the subordinate commander to deploy forces away from the FOB to non-FOB areas. Enabled by the robust data mart network architecture, the commander is able to receive synchronization updates from subordinates operating away from the FOB in order to deliver CS/CSS. The drill down access provides a SOP by which the commander is able to evaluate the multidimensional hierarchy cube in order to anticipate shortfalls, reallocate resources, and maximize operational efforts through coordination with HHQ/adjacent AOR commanders. This is possible due to the mobile device's accessibility of Layer 1 (metadata layers) and Layer 2 (data views: raw and summary) located at the local tactical cloudlet. As shown in Figure 49, both pictures leverage the same color usage as an indicator of the same metadata present in both layers.

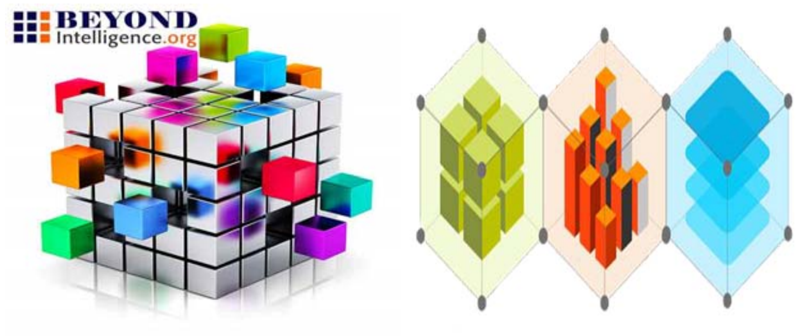

Figure 49. Metadata layers and Data views (Raw and Summary)

The shared data cube model acts as the organizational container with shared metadata for all warfighting applications. This will allow the performance of data exploitation supporting increased BFSA. The advanced analytics performed by the computerized DSS in the HHQ data mart create a single depiction of the truth that is needed in a complex decision-making environment (Power, 2008, pp 121–140). The decision-makers leverage the mobile device's drill down capability within warfighting applications to go from a wider spatial area to a smaller spatial area with finer spatial resolution as shown in Figure 50. The decision-makers require the ability to navigate to another warfighting application's spatial area, while maintaining the same drilled down spatial resolution.

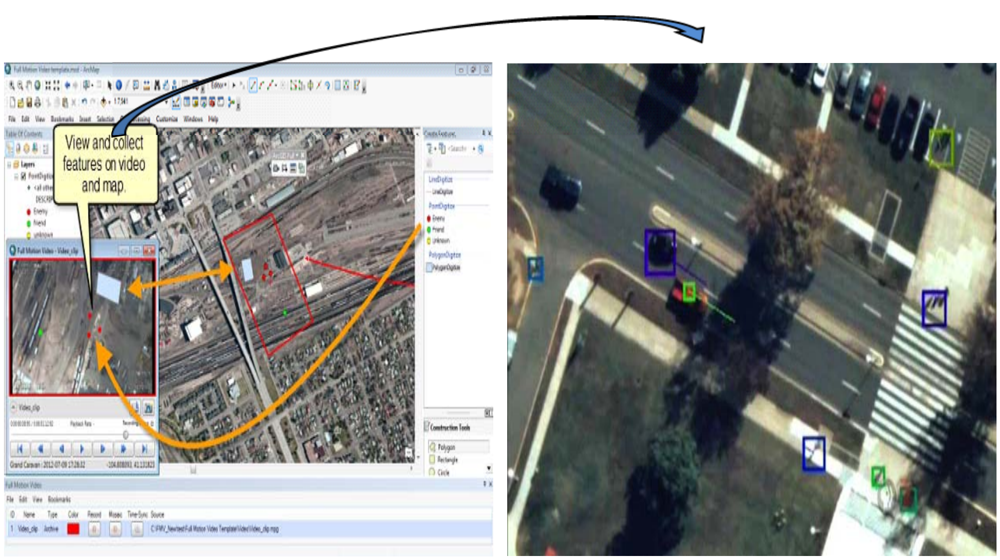

Figure 50. Example Drill Down Within FMV Application

Power (2008) noted the below listed advantages of leveraging this technology:

- Encouraged fact-based decisions
- Improved decision quality
- Improved efficiency and effectiveness of decision processes

Due to the inherent biases associated with human cognitive decision-making based on information presentation and availability, decision-makers can be influenced both positively and negatively without the aid of computerized DSS (Power, 2008, pp 121–140). Individual fixation on initially received information influences interpretation of subsequent received information. Furthermore, recent information is prioritized higher and receives the most attention by decision-makers while historical information is often discounted or forgotten (Power, 2008, pp 121–140). The cube at your mobile device and organization requires an aging policy for summarization of raw data. Current data moves from near-time to past-time archived states. This requires constant summarization of data summaries previously performed as seen in Figure 51.

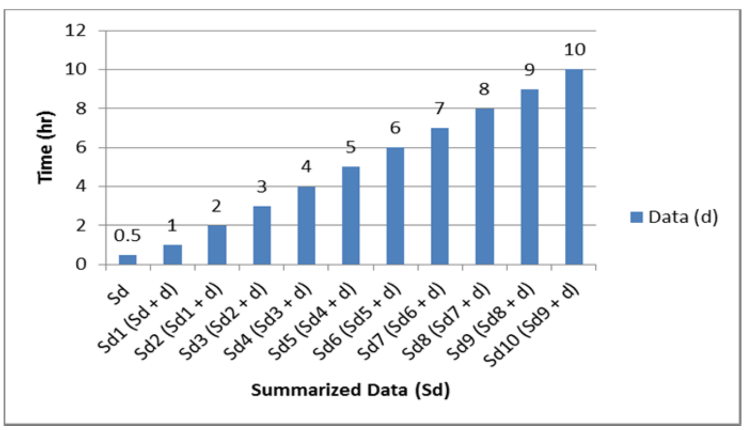

Figure 51. Data Summarization Over Time

B. USER INTERFACES: OLAP VS TRANSACTIONAL

As the flow of intelligently fused operational data matriculate from the enterprise level down to the tactical cloudlet for further synthesis using analytics from DWM, the locally stored data mart provides near-real time (subject to D-DIL conditions) synchronized data and metadata to the distributed data marts allowing for continual updates to/from the edge user's data views. The mission requirements necessitate overlapping network area coverage in order to ensure the overlap of SOPs among the decentralized units; to facilitate the conduct of distributed operations under the purview of AOR commanders who define commander's critical information requirements (CCIR). The users of different data marts have a need to share useful data and metadata across their organizational boundaries. The accurate and update-to-date characteristics (location, end-strength, etc.) of friendly, hostile, and civilian aid forces are essential to some warfighting applications, which require summarization of the topologies of the graph summary views for analysis. Nesamoney et al. (2000) warned the deployment of completely disjointed data marts would require the timely recreation of the mission critical metadata needed from another data mart. This duplication of effort coupled with the existing inability to effectively coordinate the usage of shared metadata would be resolved with the framework depicted in Figure 52.

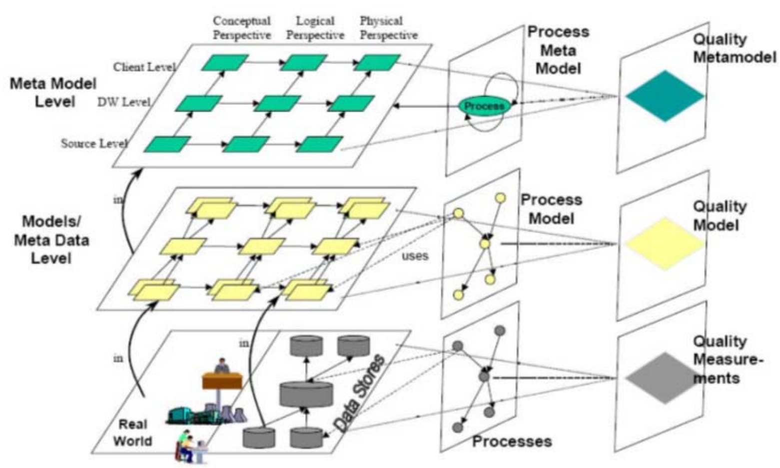

Figure 52. Framework for Data Mart Architecture (from Reddy et al., 2010)

As seen in Figure 52, the meta model level separates and categorizes data mart objects into their respective data marts (Reddy, 2010). Nesamoney et al. (2000) stated:

> The sharing of metadata becomes even more advantageous for global organizations with dispersed teams trying to solve similar or related data analysis problems using an integrated computing approach. In such organizations, coordination of efforts relies heavily on network computing and effective use of knowledge and resources developed by different

departments, groups, or teams. Indeed, the ability to share and reuse metadata within and across data marts deployed on intercommunity clouds becomes extremely important as the data marts on the cloud become more interdependent and various organizational units attempt to collaborate more closely and effectively.

The metadata level process model can be viewed as the workflow model used within the DOD. Exercising the workflow model embeds the analytics in the process steps. The edge user well-connected to the local tactical cloudlet is able to query the stored analytics and download what they need to their mobile device. Once the edge users encounter a D-DIL environment, they are no longer able to access this critical capability. The disadvantaged user has the opportunity to create analytics on their mobile device that can be compared to what was previously stored until reconnection to the local tactical cloudlet occurs.

These update driven high performance data marts store in advance information from integrated heterogeneous sources and perform on-line analytical processing (OLAP) in support of decision-making. When connected, the mobile device update and extract function receive time sensitive intelligence products (imagery and video) from HHQ via the tactical cloudlet that enable information dominance in a fluid environment. In addition to numeric (including METOC grids), the OLAP cube supports the summarization of pixels for imagery, video (including FMV), and radar. This would provide the edge user and other echelons within the AOR with a tactically acceptable good enough data management solution for the conduct of the exploitation preceding the action.

The multidimensional graphic can be viewed as a slice of the cube that can be queried by multidimensional extensions (MDX) API. Since the MDX API is designed for querying multidimensional and hierarchically organized metadata, it is more flexible than the transactional (online transaction processing [OLTP]) user interface that is primarily used in conjunction with relational tables. Organized into convoluted schemas, OLTP systems is the vector for delivering original information to data marts, while OLAP systems aid in the analysis of the received information as seen in Figure 53. The goal of OLAP in the hands of the decision-maker at the tactical edge must be included in the master data management (MDM) strategy thus making it imperative to store MDM transactions within this cube. The continual data summarization process graphically displayed in Figure 53 may not always be beneficial to the decision-maker's DSS. There needs to exist an ability to identify metrics that would be used toward the isolation and retrieval of critical information from the aggregation process. This essential information may be of particular importance to the commander operating in the D-DIL environment. It needs to be readily available at the data mart in order to query transactions needed for the commanders at the last tactical edge mile.

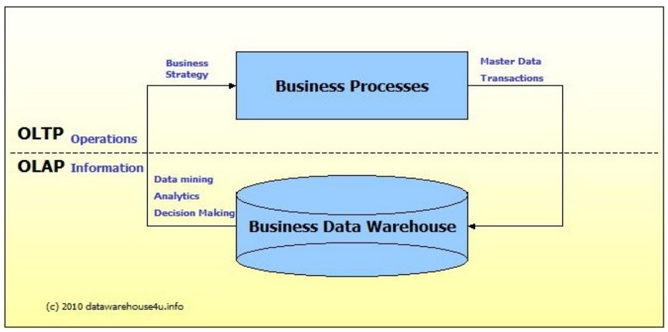

Figure 53. OLAP vs. OLTP (from datawarehouse4u.info, 2010)

A side-by-side comparison of OLTP and OLAP is outlined in Figure 54:

	OLTP System Online Transaction Processing (Operational System)	OLAP Online Analytical Processing (Data Warehouse)
Source of data	Operational Data; OLTPs are the original source of data.	Consolidation data; OLAP data comes from various OLAP Databases.
Purpose of data	To control and run fundamental business tasks.	To help with planning, problem solving and decision support
What the data Reveals	A snapshot of ongoing business processes	Multi-dimensional views of various kinds of business activities
Inserts and Updates	Short and fast inserts and updates initiated by end users.	Periodic long-running batch jobs referesh the data
Queries	Relatively standardized and simple queries Returning relatively few records.	Often complex queries involving aggregations
Processing Speed	Typically very fast.	Depends on the amount of data involved; batch data refreshes and complex queries may take many hours; query speed can be imporved by creating indexes
Space Requirements	Can be relatively small if historical data is archived.	Larger due to the existence of aggregation structures and history data; requires more indexes then OLTP
Database Design	Highly normalized with many tables.	Typically de-normalized with fewer tables; use of star and/or snowflake schemas
Backup and Recovery	Backup religiously; operational data is critical to run the business, data loss is likely to entail significant monetary loss and legal liability.	Instead of regular backups, some environmentals may consider simply reloading the OLAP data as a recovery method.

Figure 54. Comparison of OLTP and OLAP (from Monica, 2012)

C. OPERATIONS FOR DISADVANTAGED USERS

Edge users primarily operate in D-DIL environments that routinely experience the full spectrum of degraded networked connectivity. Although the last two operational environments are detrimental for highly mobile forces and is counteractive to their effort to gain and maintain a SOP, the disconnected environment isolates the edge user's mobile device from the edge resource servicing local cloudlet (PaaS/DaaS); resulting in data model mis-synchronization. Unable to obtain up-to-date near real-time information, the mobile device is limited in its ability to enhance the D2D cycle for the warfighter due to the inability to access consolidated, up-to-date data located inside HHQ data mart. The loss of contact with the up-to-date data is clearly worse than not paying enough attention to the aging data. Until network connectivity is restored, the edge user is forced to perform analytics using the currently displayed snapshot that was previously obtained during the last network synchronization without the benefit of performing queries against HHQ data mart with the truth as they know it.

Edge users whose dismounted operations extend beyond the distributed data mart network architecture operate in the unknown information space where information synchronization is no longer available. This is the result of the commander not having a previous requirement to explore this part of their AOR. In order to increase BFSA, the commander leverages overhead imagery assets either organically assigned or requested from HHQ/external sources (e.g., National Reconnaissance Office). The collected information is subsequently disseminated to the local tactical cloudlet where data aggregation and summarization is performed. Through the mobile device, the edge user is then able to query the local tactical cloudlet and receive the updated information needed to reacquire SOP. The speed in which this process is performed is dependent upon the D-DIL conditions.

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VI. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to analyze the requirements and feasibility of adapting a cloud model for enabling application deployment and data dissemination capability to Marine units in an expeditionary environment through a mobile device. The objectives of this examination were to critically evaluate current/future decision-making requirements of the edge users in a D-DIL environment; also, detailing the potential warfighter benefits of USMC procuring and adopting a tactical cloudlet solution that extends the enterprise end-to-end architecture to the company and below at the tactical edge. In order to do this, Chapter II's research assessed current C2ISR capability gaps and current equipment shortfalls. Next, Chapter III continued the company and below evaluation of fielded PoR SoS and developed requirements for future innovation. Chapter IV outlined a design strategy and design specifications for the development of a prototype. Finally, Chapter V conducted a holistic analysis of DSS and its requirements needed to operate in a D-DIL environment.

A. NEXTGEN SYSTEM REQUIREMENTS

Chapter II showed that capability gaps exist due to legacy systems being incapable of meeting the current C2ISR requirements at the company and below. The requirements in Appendix C and Table 6 helped shape and answered Research Question three in Chapter I.c of what future technology innovations and equipment requirements are necessary to operate a mobile device in a D-DIL environment.

Table 6. Capability Requirements for Future Mobility (from Marine Corps Combat Development Command, 2013)

Adaptive	Extensible	Interoperable	Intuitive	Modular	Networked
Performant	Pluggable	Reliable	Shared	Trusted	Universal

These capabilities generated requirements for company and below edge units to have like capabilities as users operating at major subordinate commands. This guided the research toward a tactical cloudlet/PaaS cloud solution that incorporates the use of

COTS/GOTS NextGen mobile device technology and addressed Research Questions one and two in Chapter I.c.

B. REQUIREMENT ANALYSIS FOR FUTURE ALTERNATIVES

In Chapter III, an evaluation of the C2ISR requirements at the company and below was performed. Additionally, the current inventory of C2ISR equipment was examined to determine if they met the needs of the warfighter. As seen in Table 4, organic communication assets primarily consist of single channel and multichannel radio systems whose inadequate data throughput capabilities are insufficient in meeting the IER. Due to limitations of current equipment, edge units require access to C2ISR assets and personnel IOT leverage all available intelligently fused products that decrease the D2D cycle. Lack of access to PWM diminishes the value of the DWM. Bandwidth constricted C2 systems degrade the ability for the decision-maker to observe-orient-decide-act within a dynamically changing fluid environment due to a degraded access to the DWM. Consequently, decision-maker's CWM suffers resulting in slow and poor decision quality.

Chapter III considered the expeditionary focus of the Marine Corps and developed requirements for a system capable of enhancing edge unit capabilities in a D-DIL environment. The recommended tactical cloudlet/PaaS solution will enable increased flexibility and responsiveness due to accessibility of C2ISR resources via a mobile device, which addressed Research Question two in Chapter I.c. Platoon level patrols equipped with a mobile device with access to a well-connected tactical cloudlet would be able to view sensor applications in near real-time. In addition, Chapter III discussed technical interoperability and physical requirements for the mobile device.

C. FUTURE HARDWARE DESIGN AND PROTOTYPE PLAN

The focus of Chapter IV was the development of required design specifications needed to produce a notional DODIN compatible prototype using existing mature technologies. Chapter IV answered Research Question four in Chapter I.c by evaluating mobile device's ability to navigate between critical C2ISR applications due to the intensive computational data processing performed on the backend at the tactical cloudlet/PaaS platform. COTS/GOTS, such as Raytheon's OFTCS architecture, provided a working proof of concept design whose utility would reduce the R&D timeline and serve as potential cost savings mechanism. The mobile device requirements outlined by Young and Ishii (2012) are applicable and served as a basis for the prototype design. Ease of use for the end-user remained a driver, along with scalability, redundancy, and security. The analysis determined that navigational capability between warfighting applications and sensors should be intuitive to the user. Minimal data entry should be required from the tactical users; data such as friendly location and call-sign should be auto-populated. Enemy locations should be obtained by overhead imagery which captures and transmit the data down to the mobile device within view and the tactical cloudlet/PaaS solution. In addition, a highly robust anti-jamming/anti-spoofing capability embedded in the mobile device is required for integration into the tactical cloudlet/PaaS solution.

D. FUTURE SOFTWARE DESIGN AND PROTOTYPE PLAN

In Chapter V, the researchers performed an in-depth analysis of the cloudlet computing architecture. The multi-dimensional data model was introduced which depicted how a decision-maker would query and retrieve actionable intelligence from the data mart using a mobile device. Another concept introduced was the computerized DSS, which is designed to aid the decision-making loop. The computerized DSS relies on the availability of the data marts in order to provide the decision-maker with SOP by performing drill drown/roll up functions within and across warfighting applications sharing those data marts. The existence of the warfighting applications sharing a data cube model allows for the computerized DSS to perform advanced analytics on information stored at the tactical cloudlet. Local cloudlet based capability is available to the decision-makers as long as they are in a well-connected environment; thus, the researchers examined the degraded capability of the decision-maker in the following two scenarios: 1) upon entry into a completely disconnected environment or 2) upon entry into an area not subjected to an intelligence preparation of the battlespace (IPB). When isolated and unable to receive up-to-date information, the decision-maker is completely reliant on the robustness of the information locally stored on the mobile device. This presents a unique set of circumstantial challenges. The decision-maker needs to determine whether he/she has to act based on available information or wait until connectivity is restored. Those choices must be carefully weighed depending on the operational situation. Depending upon D-DIL conditions, the latter scenario is the ideal fit for the tactical cloudlet solution. In this case the decision-maker, armed with the mobile device, would encounter time sensitive situations necessitating immediate actions and adjustments in response to the evolving threat. The computerized DSS would receive intelligently fused data streams based on continuous queries on the local cloudlet. The decision-maker would leverage live OLAP capability within the data mart. This would allow the decision-maker to issue orders across the temporal, spatial, and organizational hierarchies in a multi-dimensional information space. Chapter IV coupled with the aforementioned capability also addressed Research Question four in Chapter I.c.

E. RECOMMENDATIONS FOR FUTURE RESEARCH

There is a lack of previous research in the application of commercial mobile devices in a tactical environment. During the course of this research, the researchers identified several key areas that were either beyond the scope of this research or should be analyzed in future research:

- Development of Development Strategy
- Willingness to pay and total ownership cost
- Spectrum licensing costs
- Accreditation process
- Encryption policy and risk analysis
- Personnel training requirements
- Cloud model (Private vs. Hybrid vs. Public)

The commercial sector continues to conduct research and development (R&D) in mobile device innovation. Factoring in size and weight and its effect on mobility, Marine Corps Systems Command (MCSC) has pursued the Handheld C2 project which incorporates COTS/GOTS mobile device technologies ISO mobile tactical units. MCSC should conduct analysis of alternatives comparing GOTS and COTS solutions leveraging research conducted by government academia including Naval Postgraduate School.

APPENDIX A. RIFLE COMPANY T/O

Table of Organization Infantry Rifle Company (USMC Total Force Structure Management System Unit TO&E Report, 2014a)

Recap by MOS

M11163 - RFL CO A 1/5 1ST MARDIV

	BMOS	SES5	O10 E9 SES4	O9 E8 SES3	O8 E7 SES2	O7 E6 SES1	O6 E5 C15	O5 E4 C14	O4 E3 C13	O3 E2 C12	O2 E1 C11	O1 C10	W5 C9	W4 C8	W3 C7	W2 C6	W1 C5	C4	C3	C2	C1	Total
1 CHARGEABLE 1 MARINE 1 OFFICER	0302									1	5											6
1 CHARGEABLE 1 MARINE 1 OFFICER										1	5											6
1 CHARGEABLE 1 MARINE 5 ENLSTED	0111								1													1
	0231							1														1
	0311						10	29	55		28											122
	0331						3	6	6		6											21
	0341						1	3	3		3											10
	0351						1	3	3		6											13
	0369				1	5																6
	0481							1														1
	8999			1																		1
1 CHARGEABLE 1 MARINE 5 ENLSTED				1	1	5	15	43	68		43											176
Summary				1	1	5	15	43	68	1	48											182

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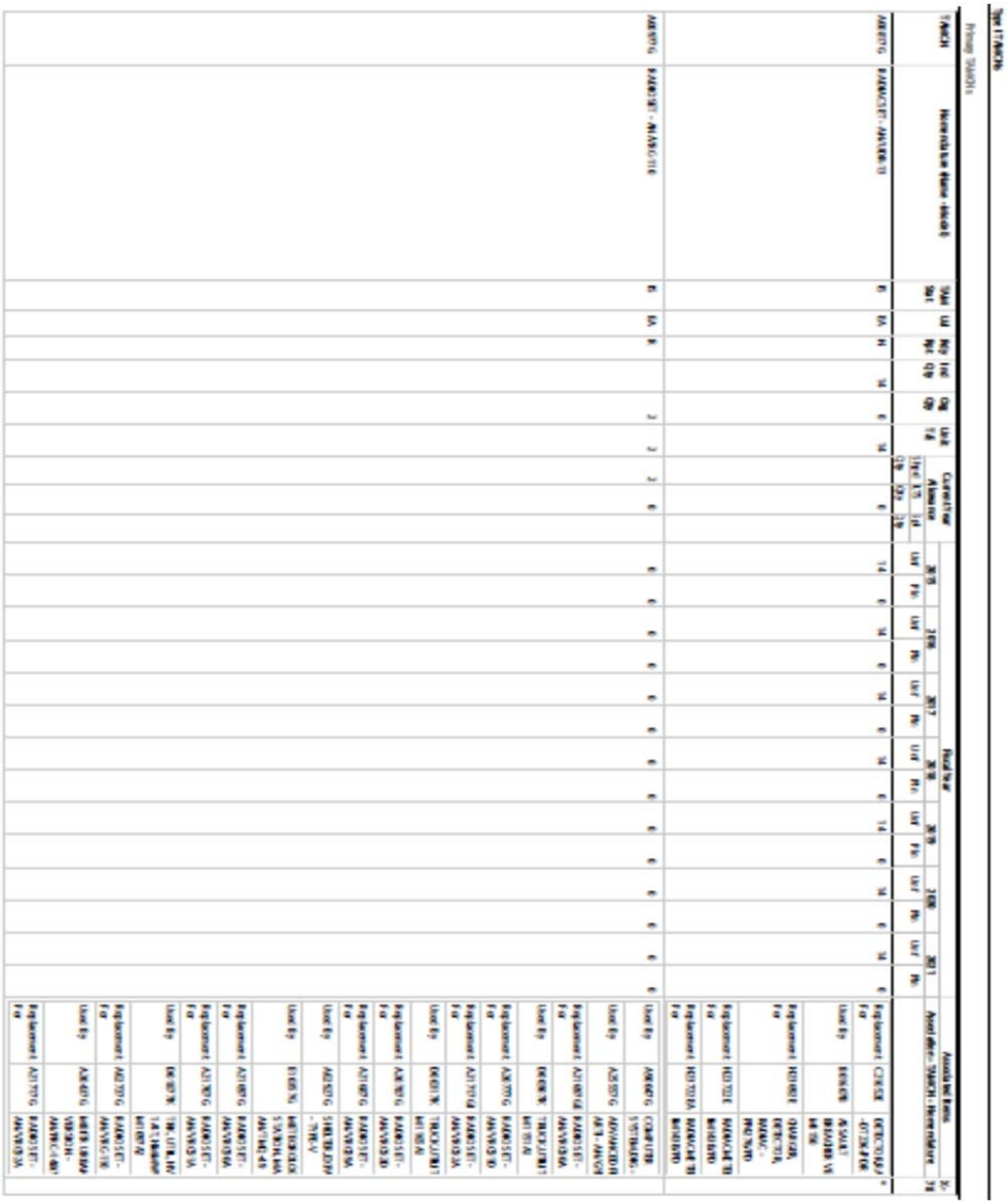
APPENDIX B. RIFLE COMPANY T/E

Table of Equipment Infantry Rifle Company (USMC Total Force Structure Management System Unit TO&E Report, 2014a)



EQUIPMENT DENSITY LIST

M11103 - RRL CO A 1/5 1ST MARDIV

TAMCN	Nomenclature (Name - Model)	TAM Stat	UI	Rep Rpt	Ind Qty	Org Qty	Unit Tot	Current Year Allowance Shpd Qty	LTS Qty	Spl Qty	Fiscal Year 2015 Unf	2015 Fin	2016 Unf	2016 Fin	2017 Unf	2017 Fin	2018 Unf	2018 Fin	2019 Unf	2019 Fin	2020 Unf	2020 Fin	2021 Unf	2021 Fin	Associated Items Association	TAMCN	Nomenclature	X-78
																									Used By	D0022?K	TRUCK,UTILIT M1152A1	
																									Used By	D1158?K	TRUCK,UTILIT M1123	
																									Used By	D5080?B	CARRIER,CAR M1087	
																									Used By	A01297G	RECEIVER-TRANSMITTE RF-300H-HHK	
A01187G	RADIO SET - AN/PRC-153(V)1	B	EA	N		176	176	176	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	Used With	H0016?B	HEADSET,ELECTRICAL - K-D5042	
																									Used With	A7517?G	TEST SET,RADIO - AN/USM-718A	
A01287G	MULTI-BAND FREQUENC - AN/VRC-110(V)2	B	EA	N		0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	Used By	D0040?K	MINE RESISTANT VI - GUFAF	
																									Used With	A7517?G	TEST SET,RAD - AN/USM-71	
																									Used By	D0027?K	MINE RESISTANT VI - CAT II A1 ER	
																									Used By	D0025?K	MINE RESISTANT VI - CAT I A1 ISS	
																									Replacement For	A2164?GA	RADIO SET - AN/VRC-103(V)	
																									Replacement For	A2164?G	RADIO SET - AN/VRC-103(V)	
																									Used By	D0023?K	MINE RESISTANT VI - COUGAR CAT II A4	
																									Used By	D5080?B	CARRIER,CAR - M1087	
A01297G	RECEIVER-TRANSMITTE - RF-300H-HHK01	B	EA	R		34	34	34	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	Used With	A0497?G	RADIO SET - AN/VRC-110	
																									Used By	A0424?G	SOLAR PORTABLE ALTE - 7853S-1000	
																									Used By	H0016?B	HEADSET,ELECTRIC - K-D5002	
																									Used With	A0135?G	RADIO SET - AN/VRC-112	
																									Replaced By	A0487?G	WIDEBAND TACTICAL HAND HELD RADIO	
A01387G	RADIO SET - AN/PRC-117G(V)2	B	EA	R		4	4		0		4	0	4	0	4	0	4	0	4	0	4	0	4	0	Used By	A0051?G	REMOTE CONTROL RADI - OK-685/PRC	
																									Used By	H0016?G	ADAPTER,POWER SUPPL - MBPU-H3	
																									Used With	H0021?G	ANTENNA - RF-291-AT001	

Equipment Organization

MTT103 - RRL CO A 1/5 1ST MARDIV

TAMCN	Nomenclature (Name - Model)	TAM Stat	UI	Rdy Rpt	Ind Qty	Org Qty	Unit T/E	Current Year Allowance Shpd Qty	LTS Qty	Spl Qty	Fiscal Year 2015 Unf	Plc	2016 Unf	Plc	2017 Unf	Plc	2018 Unf	Plc	2019 Unf	Plc	2020 Unf	Plc	2021 Unf	Plc	Associated Items Association - TAMCN - Nomenclature	[illegible]
																									Used By A04242G SOLAR PORTABLE ALTE - 78535-100299	
A01527G	RADIO SET - AN/VRC-114(V)1	IS	EA	N		1	1		0		1	0	1	0	1	0	1	0	1	0	1	0	1	0	Used By A00517G REMOTE CONTROL RADIO - OK-68S/PRC Used With H0012G ANTENNA - RF-291-AT001	
A04242G	SOLAR PORTABLE ALTE - 78535-100299	IS	KT	N		18	18		0		18	0	18	0	18	0	18	0	18	0	18	0	18	0	Used With A20487G RADIO SET - AN/PRC-117F(V)1C Used With A20447G RADIO SET - AN/PRC-148(V)3C Used With A01987G RADIO SET - AN/PRC-117G(V)2 Replacement For H00112G SOLAR PORTABLE ALTE - 78535-100799 Used With A01287G RECEIVER-TRANSMITTER - RF-300H-HH001 Used With A20797G RADIO SET - AN/TRC-170F	
A08747G	COMMAND SYSTEM,TACT - AN/UYQ-48B(V)2	IS	EA	N		1	1		0		1	0	1	0	1	0	1	0	1	0	1	0	1	0	Used With A08737G COMMAND SYSTEM,TACT - AN/UYQ-90B(V)2 Used With A02067G USB ENTAR - IS V-5B Used By A08737G COMMAND SYSTEM,TACT - AN/UYQ-90B(V)2	
A12487G	RECEIVER,RADIO NAV - AN/PSN-13(B)	IS	EA	N		6	6	6	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	Used By E13787K RECOVERY VEHICLE,FU - M88A2 Used By A50047G COMMUNICATIONS DATA - 00001A0005 Used By E07967K ASSAULT VEHICLE,FUL - AAVC7A1 RAM/RS Used By A00217G COMMUNICATIONS DATA - AN/TYQ-101A Used By A50057G AIR DEFENSE COMMUNI - AN/MEQ-124 Used By A00257G COMMUNICATION RELAY - AN/MSQ-124 Used By E08467K ASSAULT VEHICLE,FUL - AAVP7A1 RAM/RS Used By E08567K ASSAULT VEHICLE,FUL -	

Equipment Organization

M11163 - RRL CO A 1/5 1ST MARDIV

TAMCN	Nomenclature (Name - Model)	TAM Stat	UI	Rep Rpt	Ind Qty	Org Qty	Unit T/E	Current Year Allowance Shpd Qty	Current Year Allowance ATS Qty	Current Year Allowance Spl Qty	2015 Unf	2015 Fin	2016 Unf	2016 Fin	2017 Unf	2017 Fin	2018 Unf	2018 Fin	2019 Unf	2019 Fin	2020 Unf	2020 Fin	2021 Unf	2021 Fin	Associated Items: Association - TAMCN - Nomenclature	X-78
																									AANR7A1 RAMARS Used By - A50077G - TESTSUITE,AIR DEFE - AN-MSQ-124 Used By - A14467G - RADAR SET - 000048000 Used With - B0495 7G - DETECTING SET,MINE - 011007-2-AY Used By - B0114 7B - BOAT,BRIDGE ERECTIO - MRC25 Used With - B0132 7B - ENGINEERING FIELD PLANNING, RECONNAISSANCE, SURVEYING, AND SKETCHING SET (HRED)	
A20427G	RADIO SET - AN/PRC-150 (C)	IS	EA	R		2	2		0		0	2	0	0	0	0	0	0	0	0	0	0	0	0	Replacement For - A20487G - RADIO SET - AN/PRC-104B(V) Used With - A75177G - TEST SET,RADIO - AN/USM-718A	
A20487G	RADIO SET - AN/PRC-117F(V)1C	IS	EA	R		6	6		0		0	6	0	0	0	0	0	0	0	0	0	0	0	0	Replacement For - A20487G - RECEIVER-TRANSMITTE - AN/PRC-113(V)3 Used With - A75177G - TEST SET,RADIO - AN/USM-718A Used By - A50277G - TRAINING SET,TARGET - I Used By - A04242G - SOLAR PORTABLE ALTE - 7855-1 Used By - H00182E - HEADSET,ELEC - K05182 Used By - A01887G - COMMUNICAT SUBSY - AN/TYQ-149V	
A25467G	COMPUTER SYSTEM,DIG - SEVERAL	IS	EA	N		6	6	10	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	Used By - A02797G - TARGET PROCESSING S - AN/TSQ-267 Used By - E15007M - LAUNCHER,ROCKET,M - M142	
A80017G	TRACKER,CELESTIAL P	IS	EA	N		0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	Used By - E03707K - RECOVERY VEHICL - M88A2 Used By - E0947M - LIGHT ARMORED V - LAV-25 A2 Used By - E0796K - ASSAULT VEHICLE, AAVC7A1 RAMARS Used By - D01147K - TRUCK,WRECKER - MK36 Used By - D00067K - TRUCK,UTILITY - M1151A1 Used By - D00877K - TRUCK,TRACTOR - MK16	

Equipment Organization

M11110 -RR COA 1-5 1ST MARDIV

TAMCN	Nomenclature (Name - Model)	TAM Stat	UI	Rdy Rpt	Ind Qty	Org Qty	Unit T/E	Current Year Allowance			Fiscal Year														Associated Items			X-78
											2015		2016		2017		2018		2019		2020		2021		Association - TAMCN - Nomenclature			
								Stpd Qty	LTS Qty	Spl Qty	Unf	Fin	Unf	Fin	Unf	Fin	Unf	Fin	Unf	Fin	Unf	Fin	Unf	Fin				
																									Used By	D1125TK	TRUCK,UTILITY - M1045A2	
																									Used By	D0015TK	TRUCK,WRECKER, -AMK36	
																									Used By	D1062TK	TRUCK,TAA,SUW MK27A1	
																									Used By	D1073TK	TRUCK,TAA,DUM MK29A1	
																									Used By	D0003TK	TRUCK,ARMORED, -AMK23A1	
																									Used By	D0007TK	TRUCK,ARMORED, -AMK25A1	
																									Used By	E0056TB	LIGHT ARMORED ' LAV-R A2	
																									Used By	D0034TK	TRUCK,UTILITY - M1165A1B3 FKS	
																									Used By	D0031TK	TRUCK,UTILITY - M1165A1	
																									Used By	D0013TK	TRUCK,TRACTOR, -AMK31A1	
																									Used By	D1063TK	HIMARS RE-SUPPL AMK37	
																									Used By	D0886TK	TRUCK,CARGO - M	
																									Used By	E0015TB	CARRIER,BRIDGE L M60A1	
																									Used By	E0846TK	ASSAULT VEHICLE, AAVP7A1 RAM/RS	
																									Used By	E0856TK	ASSAULT VEHICLE, AAVR7A1 RAM/RS	
																									Used By	E1035TG	METEOROLOGICAL STATION, MANUA AN/TMQ-45	
																									Used By	D1001TK	TRUCK,AMBULANC M997A3	
																									Used By	E0948TB	LIGHT ARMORED ' LAV-L A2	
																									Used By	D0032TK	TRUCK,UTILITY - M1167A1	
																									Used By	D0018TK	TRUCK,TAA,CAR MK23A1	
																									Used By	E0942TM	LIGHT ARMORED ' LAV-AT A2	
																									Consists Of	A1260?GK	NAVIGATION SET: AN/PSN-13(A)	
																									Used By	E1500TM	LAUNCHER ROCKE M142	
																									Used By	E1035TM	GUIDED MISSILE E AN/TWQ-2	
																									Used By	E1888TM	TANK,COMBAT FU M1A1	
																									Used By	D1002TK	TRUCK,AMBULANC M1035A2	

Equipment Organization

MTT103 - RR CO A 1/5 1ST MARDIV

TAMCN	Nomenclature (Name - Model)	TAM Stat	UI	Rep Rpt	Ind Qty	Org Qty	Unit T/E	Current Year Allowance Shpd Qty	Current Year Allowance LTS Qty	Current Year Allowance Spl Qty	2015 Unf	2015 Pln	2016 Unf	2016 Pln	2017 Unf	2017 Pln	2018 Unf	2018 Pln	2019 Unf	2019 Pln	2020 Unf	2020 Pln	2021 Unf	2021 Pln	Associated Items Association - TAMCN - Nomenclature	X-78
																									Used By - D0001?K - TRUCK,TAA,TRAC MK31 A1 Used By - E0947M - LIGHT ARMORED V LAV-M A2 Used By - D0027K - TRUCK,UTILITY - M1152 A1 Consists Of - A0017GA - ENCRYPTIONDEVICE KIV-? Used By - E0947B - LIGHT ARMORED V LAV-C2 A2 Used By - D0007K - TRUCK,ARMORED, AMK27 A1 Used By - D0007B - CARRIER,CARGO -	
A00207G	COMPUTER SYSTEM,DIG - SEVERAL	IS	EA	N		18	18	26	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		
A00717G	COMPUTER SYSTEM,DIG - MCHSP AN/T-37 P(V)	IS	EA	N		0	0	3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		
A01002B	COMPUTER SYSTEM,DIG - SEVERAL	IS	EA	N		0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		
E0047?B	CAMERA, DIGITAL CHEAP	PL		N		51	51		0		51	0	51	0	51	0	51	0	51	0	51	0	51	0		
E0472?B	DEMOLITION SET, EXPL	IS	KT	N		3	3	3	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		
C00042E	VIEWING SET, INFRARE - HH11	IS	EA	N		5	5	5	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		
C00152E	INSERT,SMALL ARMS P - 95642	IS	SE	N	182	0	182		0		182	0	182	0	182	0	182	0	182	0	182	0	182	0	Used By - C? - INSERT,SMALL ARMS P - 85424 Used By - C? - VEST,SMALL ARMS PRO - N/A Used By - C? - VEST,TACTICAL MODUL - N/A Used By - C? - KIT,FSE,INDIVIDUAL - CONFIG A	*
C00292F	DRAWERS,COLD WEATHE	IS	PR	N	182	0	182		0		182	0	182	0	182	0	182	0	182	0	182	0	182	0		*
C00302E	KIT,MECHANICAL BREA	IS	KT	N		6	6	6	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0		
C00402E	KNEEPAD (LARGE) - MEDIUM	IS	PR	N	182	0	182		0		182	0	182	0	182	0	182	0	182	0	182	0	182	0	Replacement For - K47?? - KNEE PADS EXTERNAL - N/A	*
C00412E	ELBOW PADS,EXTERNAL - SMALL	IS	PR	N	182	0	182		0		182	0	182	0	182	0	182	0	182	0	182	0	182	0	Replacement For - K47?? - EXTERNAL ELBOW PADS - N/A	*
C00512B	COVERALLS,COMBATIVE	IS	EA	N		0	0		0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	Used By - C2? - GLOVES,NUCLEAR,BIOL DISP MIL? Used With - C2? - OVERBOOTS,LIGHTWEIG	*
C00612F	CARRIER, SMALL ARMS PROTECTIVE BODY ARMOR - N/A	IS	EA	N	182	0	182		0		182	0	182	0	182	0	182	0	182	0	182	0	182	0	Replacement For - C0061?A - CARRIER,SCAL PL - 3-SM Replacement For - C0061?F - CARRIER, SMALL ARMS PROTE BODY ARMOR N/A Replaced By - C0061?F - CARRIER, SMALL ARMS PROTE BODY ARMOR N/A	*

APPENDIX C. MAGTF C2 CAPABILITY

Top 5 Net-Enabled C2 Capability POM-14 Marine Corps Gap List from MAGTF C2 Roadmap (Marine Corps Combat Development Command, 2013)

Task ID	Task Title	MGL Tier	MGL Rank	Gap ID	Gap Statement	Gap Title
C.03–03	3.2 Employ friendly force tracking capability, provide access and integrate information on location, identity, status, capabilities, and limitations of friendly forces (BFSA), collaboratively assess and share implications.	1	10	C.03–03-G1	Inability to provide situation awareness and friendly position location across the MAGTF to the tactical level.	Situation awareness
C.03–12	3.5 Present tailored relevant, synthesized, actionable information to promote understanding.	1	17	C.03–12-G1	Information flow to the decision-maker used to provide situation awareness is incomplete and not timely.	Common Operational Picture
C.19–03	11.3 Acquire additional network resources on demand.	1	22	C.19–03-G1	Insufficient ability to provide sufficient information transport capacity (Mbps) at the halt. No capacity to provide additional capacity on-the-move.	Network Capacity

C.21–01	13.1 Transmit.	1	18	C.21–01-G1	Insufficient bandwidth to provide for multiple circuits and networks to support operational requirements for maneuver units (on-the-move).	Systems Throughput Capacity
C.06–55	6.8 Validate targets prior to attack.	2	29	C.06–55-G1	Limited ability to validate targets and non-combat desired effects in near real time.	Target Validation
Task ID	Task Title	MGL Tier	MGL Rank	Gap ID	Gap Statement	Gap Title
C.03–03	3.2 Employ friendly force tracking capability, provide access and integrate information on location, identity, status, capabilities, and limitations of friendly forces (BFSA), collaboratively assess and share implications.	1	10	C.03–03-G1	Inability to provide situation awareness and friendly position location across the MAGTF to the tactical level.	Situation awareness
C.03–12	3.5 Present tailored relevant, synthesized, actionable information to promote understanding.	1	17	C.03–12-G1	Information flow to the decision-maker used to provide situation awareness is incomplete and not timely.	Common Operational Picture

C.19–03	11.3 Acquire additional network resources on demand.	1	22	C.19–03-G1	Insufficient ability to provide sufficient information transport capacity (Mbps) at the halt. No capacity to provide additional capacity on-the-move.	Network Capacity
C.21–01	13.1 Transmit.	1	18	C.21–01-G1	Insufficient bandwidth to provide for multiple circuits and networks to support operational requirements for maneuver units (on-the-move).	Systems Throughput Capacity
C.06–55	6.8 Validate targets prior to attack.	2	29	C.06–55-G1	Limited ability to validate targets and non-combat desired effects in near real time.	Target Validation

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APPENDIX D. PORTABLE COMMUNICATION SYSTEMS

Man Packable Communication Systems Description from COE for ICB-C2 (Combat Development & Integration, 2012)

System	Description
PRC-117F PRC-117G	The PRC-117F is the legacy multi-band manpack radio. This system is not expected to be used at the company level and below in the 2016 timeframe. However, PRC-117F will remain in use at the battalion level and above. The more recent PRC-117G provides Marines with a wideband, software-defined radio with the ability to transmit and receive high-bandwidth simultaneous voice and text data, graphics, and video over terrestrial and celestial networks. This radio interfaces with C2 end-user devices such as laptops and handhelds. The PRC-117G can be configured with appropriate antennae, such as those provided through its Field Expedient Mount, to provide SATCOM transmission. It can also be configured for man-pack, vehicular and base station applications suitable for operation in a multi-mode service environment. This radio will be used at the company level to maintain data and voice communications with the parent battalion in all conditions.
PRC-152 PRC-152A (ANW2)	The PRC-152A WB THHR serves as a lightweight data, voice, and video transmission solution using the ANW2 waveform. It delivers modern programmable encryption and is employed at all levels from the company commander down to the squad leader. Like the PRC-117G, the PRC-152A provides an interface to C2 end-user devices for data transmission. It also acts as a handheld voice communication system between the squad, platoon, company, and adjacent units. The legacy PRC-152 is expected to phase out.
PRC-150	The PRC-150 is a leading HF technology that features Automatic Link Establishment (ALE) for secure voice and data transmission. Additionally, the PRC-150 leverages advanced frequency hopping, which ensures consistent, secure communications even in the presence of jamming. It provides long-haul communications at the platoon level and above. In the event that SATCOM capabilities are disabled or unavailable to platoons or companies during disaggregated and distributed operations, the PRC-150 system provides the only long-haul capability below the company level.
PRC-153 IISR	The PRC-153 IISR is a type-3 encrypted, VHF line-of-sight (LOS) voice-only squad radio used to maintain communications within and between squads and fire teams. It is not a replacement or duplicate capability with the WB THHR, although it may be used to support voice communications with subordinate and parent units when environmental conditions permit.

JBC-P(H)	The JBC-P(H) is a planned handheld C2 device with a standardized software baseline providing COP viewer and collaboration / chat capabilities down to the squad level. The JBC-P(H) must be physically connected or tethered to a tactical data radio. At the squad level, this will primarily be the PRC-152A WB THHR, however it can also be used with the PRC-117G if required.
ECO Kit	Program Manager Marine Expeditionary Rifle Squad (PM MERS) has fielded a large quantity of laptops with C2 and intelligence software. These ECO Kits provide an interim solution to C2 and intelligence needs at the company, platoon, and squad levels primarily as a manpack-able system, also re-usable within a fixed COC. Along with the ruggedized laptop computer with C2 and intelligence software, the kit comes equipped with a digital camera, and cabling to connect the laptop to tactical radios (PRC-117F and PRC-117G). ECO is not expected to be a long-term solution.
TLDHS	The Target Location Designation and Hand-off System (TLDHS) is a modular, man-portable equipment suite used by the company fires support team (FiST), that provides the ability to quickly acquire targets in day, night, and near-all-weather visibility conditions via data and video transmission in near real time. It maintains interoperability with several systems including PRC-117 systems and the JTCW Gateway to incorporate fires data into the COP. However, it requires a connection to the Advanced Field Artillery Tactical Data System (AFATDS).

APPENDIX E. VEHICULAR COMMUNICATION SYSTEMS

Vehicle Mounted Communication Systems Description from COE for ICB-C2 (Combat Development & Integration, 2012)

System	Description
VRC-103	The VRC-103 is a multi-band radio system that provides a vehicular mounting and power amplification option for the AN/PRC-117F. It has four antenna parts which can be configured for SATCOM, VHF, and UHF transmission while providing embedded, type-1 encryption.
VRC-104	The VRC-104 is a vehicle-mounted PRC-150 HF tactical radio. It serves as a long-haul HF system that is ALE compatible while providing voice and data capabilities while offering Type-1 embedded NSA approved encryption.
VRC-112	The VRC-112 is a kit that amplifies and houses a single PRC-152A within a vehicle. The VRC-114(V)1 (see below) and VRC-112 radios are often in the same tactical vehicle, together providing simultaneous voice and data transmission capabilities.
VRC-110	The VRC-110 consists of two VRC-112 units (i.e., dual PRC-152A WB THHRs housed in vehicle mounts with amplifiers). This system also provides a significant data and voice capability while OTM. The VRC-110 is being fielded in armament carrying HMMWVs and it comprises two VRC-112s (see below). It is often used in convoys to maintain links between vehicles, but can also be used to maintain communications to the parent battalion.
VRC-114 (V)1	The VRC-114 (V)1 is a vehicle-mounted PRC-117G with cradle and amplifier, providing voice, text, graphics, and video capabilities OTM. Mounted C2 end-user devices, such as the JBC-P vehicle variant, will interface with this radio to send /receive data.
VRC-111 VRC-113	The VRC-111 and VRC-113 are the vehicle amplifier and the small-form adapter, respectively, for the PRC-148 MBITR. They provide a VHF capability with extended range for voice communications. The MBITR handheld itself is not used by rifle and weapons companies; it is only used in Maritime situations and for reconnaissance because of its waterproofing capabilities. The vehicle variant, however, continues to provide a significant voice communications capability at the company level.
MRC-145	The MRC-145 is a vehicle-mounted single channel ground and airborne radio system (SINCGARS) with power amplifier and two radios per vehicle. It is used as a network extension from the infantry battalion to the company. Due to its current employment as a network extension and re-transmission node, the NOTM PoP solution (see below) will be integrated into the MRC-145 vehicle.

NOTM PoP	The PoP component of NOTM is a vehicle-mounted set of equipment including a tactical data radio with OTM antenna, SATCOM OTM subsystem with antenna dish, router and switch, wireless access point, and management software with user interface. It supports OTM C2 users, but also allows dismounted Marines with C2 devices tethered to the manpack PRC-117G or PRC-152A WB THHR to transmit and access data BLOS or OTH. NOTM has the flexibility to be used for fixed operations, providing the networking and routing functions required for a fixed company COC.
NOTM SVK	The NOTM SVKs provide vehicle-mounted end-user devices with software loads similar to that used in existing COC (V)2-(V)4 workstations. The SVK in the vehicle connects through vehicle-mounted tactical data radios, such as the VRC-114, which then connects to the PoP vehicle for access to C2 applications, SIPRNet, and NIPRNet while OTM.
JBC-P Vehicle	The JBC-P vehicle variant transmits and receives individual warfighter C2 information and PLI data of friendly forces over celestial networks. It has integrated L-band SATCOM capabilities and creates a network of C2 devices installed on platforms to enable BFSA at the company level and below. In the future, the JBC-P vehicle variant will be replacing both the Joint Capabilities Release (JCR), which leverages BFT2 technology, and current the vehicle-mounted BFT system. Ultimately, JBC-P will allow two-way, BLOS communication of voice, data and images between handhelds, vehicles, and higher headquarters.

APPENDIX F. NON-MOBILE COMMUNICATION SYSTEMS

Stationary or Fixed Communication Systems Description from COE for ICB-C2 (Combat Development & Integration, 2012)

System	Description
MRC-142C	The MRC-142C is a digital wideband terrestrial transmission system offering voice and data capability, transported on a HMMVW but designed to be stationary while operational. It has a more limited data capability than the celestial VSAT and terrestrial WPPL systems.
VSAT	The VSAT is a component of the Support Wide Area Network (SWAN) FoS solutions that operates on a Ku band spectrum and provides BLOS satellite communications at fixed locations. The VSAT extends Defense Information Systems Network (DISN), SIPR and NIPR e-mail, and voice-over-IP (VoIP) services.
WPPL	The WPPL provides terrestrial wireless capability allowing users access to DISN, basic telephone services, SIPR/NIPR e-mail, and secure and unsecure voice. Only (1) will be provided by the battalion to the company, if mission requirements dictate this need. The VSAT and MRC-142C (see below) would also support the functions of the WPPL.
DDS-M	The LEM or WSM, part of the DDS-M suite of systems, provides the interface to the VSAT, WPPL, or MRC-142C to route services to workstations / laptops used at the company level. The DDS-M consists of a number of self-contained transit cases housing network servers and networking equipment that can be set up in a variety of environments.
TSM	The TSM, comprising the RSAM and DEOS, provides a flexible unit level switch with more robust voice / data switching, data transport, and bandwidth management capabilities.
JBC-P CP / TOC Kit	The JBC-P program will also provide C2 end-user devices through its Command Post (CP) variant, which will replace the BFT TOC Kits currently being used throughout the Marine Corps. This system provides a workstation with graphical representation of real-time BFSA and blue PLI updates. The larger JBC-P FoS will be a significant portion of the C2 capability at the company level and below.

JTCW / C2PC	The JTCW / C2PC software baseline is currently used in COC (V)1-(V)4. Tthe company level will operate primarily with similar thick client software applications that are configured to access remote ADS systems residing at the battalion and above. This software may be provided through the Intelligence Workstation (IW), which will be employed by the 0231 intelligence analyst at the company level, or else it will be provided through a standard MCHS laptop.
General Purpose Laptop	General purpose ruggedized laptops are a significant part of the company T/E, and represent a tool for commanders and Marines to generate a variety of reports and products using text and graphics. The software load provides the applications to support different formats and data manipulation.
ECCS RRK	The ECCS RRK is a transit case / suitcase solution containing tactical Ka-band SATCOM capabilities, networking hardware, and embedded software to enable commanders to maintain SA while OTM or OTH during semi-permanent operations. ECCS provides voice, video, and data services to small forces over SIPRNet and NIPRNet while offering COP, collaboration, and communications capabilities with higher headquarters.

APPENDIX G. EMPLOYMENT METHODS

Methods of Employment from COE for ICB-C2
(Combat Development & Integration, 2012)

Table 1: Form Factors Employed by Echelon and Condition

	Manpack	Vehicle	Stationary
Company COC Dismounted	**X**		
Company COC OTM	**X**	**X**	
Company COC Fixed			
Jump*	**X**	**X**	
Forward / Vehicle-based**	**X**	**X**	
Main	**X**	**X**	**X**
Platoon Dismounted	**X**		
Platoon OTM	**X**	**X**	
Platoon Fixed (CP)	**X**	**X**	
Squad Dismounted	**X**		
Squad OTM	**X**	**X**	
Squad Fixed	**X**	**X**	

* The systems employed for the COC OTM, Jump COC, and Forward / Vehicle-based COC may be similar or identical in some scenarios, but each COC configuration is unique.

** The Forward / Vehicle-based COC represents the use of vehicular systems to support a fixed COC, while COC OTM represents use of vehicle-mount systems in transit.

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APPENDIX H. SYSTEMS TO CAPABILITY

Systems to Capabilities Mapping from COE for ICB-C2 (Combat Development & Integration, 2012)

- **Tactical Network Access and Browsing:** this requirement area relates to systems that enable end-user devices to connect to networks, as well as devices that have basic e-mail and web-browsing applications
  - SIPRNet Access
  - SIPRNet E-mail and Web Browsing
  - NIPRNet Access
  - NIPRNet E-mail and Web Browsing
- **Free Text Message / Data Transmission (Radio):** this requirement area relates specifically to radio systems that are able to transmit in data mode, as well as provide a basic free text message and user interface
- **DISN Extension:** this requirement area relates to systems that extend DISN services to several concurrent users
- **Voice Capabilities:** this requirement area relates to systems that enable voice communications using a variety of specific media, including radios, SATCOM systems, etc.
  - Voice (Radio, Push-to-Talk)
  - Voice (Plain-Old-Telephone-System (POTS))
  - Voice (SATCOM, Push-to-Talk)
  - Voice (VOSIP)
- **Applications:** this requirement area relates to systems that can be mapped to core C2-related applications as well as general warfighting function applications; it is meant only to demonstrate the breadth of functions that any given system may provide at the company level and below
  - Chat Application
  - BFSA Application
  - COP/CTP Application
  - General Purpose Office Application (e.g., word processor, presentation, spreadsheet)
  - Fires Application and Overlay
  - Intelligence Application
  - Force Protection Application
- **Spectrums:** this requirement area relates to systems that provide voice and/or data transmission capabilities across bandwidth spectrums
  - VHF
  - UHF
  - HF
  - SATCOM (non-specific bands)

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APPENDIX I. SYSTEMS TO CAPABILITY CONT

Systems to Capabilities Mapping from COE for ICB-C2 (Combat Development & Integration, 2012)

	Company COC Fixed	SIPRNet Access	SIPR Email & Browsing Applications	NIPRNet Access	NIPR E-Mail & Browsing Applications	Data (Radio)	DISN Extension	Voice (Radio push-to-talk)	Voice (POTS)	Voice (SATCOM push-to-talk)	Voice (VOSIP)	Chat Application	Free Text Message (Radio)	BFSA Application	COP/CTP Application	General Purpose Office Applications	Fires Application & Overlay	Intel Applications	Force Protection Application	VHF	SATCOM	HF	UHF	% of Requirements
Manpack Systems	PRC-117G	x		x		x		x		x			x							x	x		x	41%
	PRC-117F (**not used at company level in 2016)	x		x		x		x		x			x							x	x		x	41%
	PRC-150					x		x					x							x		x		23%
	PRC-152A Wideband Tactical Handheld Radio (WB THHR)	x				x		x		x			x							x	x		x	36%
	PRC-153 Inter- / Intra-Squad Radio (ISR)							x												x			x	14%
	Joint Battle Command-Platform Handheld (JBC-P(H))											x		x	x		x							18%
Vehicle Mount Systems	VRC-145	x		x		x		x												x				23%
	VRC-114 (V)1	x		x		x		x		x			x							x	x		x	41%
	VRC-110	x		x		x		x		x			x							x	x		x	41%
	VRC-112	x		x		x		x		x			x							x	x		x	41%
	VRC-111 / 113							x		x										x			x	18%
	Blue Force Tracker (BFT) / JBC-P vehicle variant											x		x	x		x				x			23%
	Networking-on-the-Move (NOTM) Point of Presence (POP)	x		x		x		x	x	x	x		x								x			41%
	NOTM Staff Vehicle Kit (SVK)		x		x							x		x	x									23%
Stationary Systems	Very Small Aperture Terminal (VSAT)	x		x			x				x										x			23%
	Wireless Point-to-Point Link (WPPL)	x		x			x		x		x										x			27%
	MRC-142C	x		x			x		x		x													23%
	Transition Switch Module (TSM); Remote Subscriber Access Module (RSAM) and Deployable End Office Suite (DEOS)								x		x													9%
	Data Distribution System-Modular (DDS-M): Local Area Network (LAN) Extension Module (LEM) and Wide Area Network (WAN) Services Module (WSM)	x		x																				9%
	Expeditionary Command and Control Suite (ECCS) Rapid Response Kit (RRK)	x	x	x	x					x	x	x			x						x			41%
Other Devices	Enhanced Company Operation (ECO) (**unfunded)		x		x							x		x	x	x		x						32%
	General Purpose Laptop		x		x							x				x								18%
	TLDHS / SLATE																x							5%
	Joint Tactical COP Workstation (JTCW) / C2 Personal Computer (C2PC)		x		x							x		x	x	x	x							32%
	BATS / HIIDE																		x					5%
	Tactical Operations Center (TOC) Kit / JCB-P Command Post (CP) variant		x									x		x	x									18%
	Intelligence Workstation (IW)		x									x		x	x	x		x						27%

Company COC On-The-Move (OTM)		SIPRNet Access	SIPR Email & Browsing Applications	NIPRNet Access	NIPR E-Mail & Browsing Applications	Data (Radio)	DSN Extension	Voice (Radio push-to-talk)	Voice (POTS)	Voice (SATCOM push-to-talk)	Voice (VOSIP)	Chat Application	Free Text Message (Radio)	BFSA Application	COP/CTP Application	General Purpose Office Applications	Fires Application & Overlay	Intel Applications	Force Protection Application	VHF	SATCOM	HF	UHF	% of Requirements Mapped
Manpack Systems	PRC-117G	x		x		x		x		x			x							x	x		x	41%
	PRC-117F (**not used at company level in 2016)	x		x		x		x		x			x							x	x		x	41%
	PRC-150					x		x					x							x		x		23%
	PRC-152A Wideband Tactical Handheld Radio (WB THHR)	x				x		x		x			x							x	x		x	36%
	PRC-153 Inter- / Intra-Squad Radio (ISR)							x												x			x	14%
	Joint Battle Command-Platform Handheld (JBC-P(H))											x		x	x		x							18%
Vehicle Mount Systems	MRC-145	x		x		x		x												x				23%
	VRC-114 (V)1	x		x		x		x		x			x							x	x		x	41%
	VRC-110	x		x		x		x		x			x							x	x		x	41%
	VRC-112	x		x		x		x		x			x							x	x		x	41%
	VRC-111 / 113							x		x										x			x	18%
	Blue Force Tracker (BFT) / JBC-P vehicle variant											x		x	x		x				x			23%
	Networking-on-the-Move (NOTM) Point of Presence (POP)	x		x		x		x	x	x	x		x								x			41%
	NOTM Staff Vehicle Kit (SVK)		x		x							x		x	x									23%
Stationary Systems	Very Small Aperture Terminal (VSAT)	x		x			x				x										x			
	Wireless Point-to-Point Link (WPPL)	x		x			x		x		x										x			
	MRC-142C	x		x			x		x		x													
	Transition Switch Module (TSM); Remote Subscriber Access Module (RSAM) and Deployable End Office Suite (DEOS)								x		x													
	Data Distribution System-Modular (DDS-M); Local Area Network (LAN) Extension Module (LEM) and Wide Area Network (WAN) Services Module (WSM)	x		x																				
	Expeditionary Command and Control Suite (ECCS) Rapid Responce Kit (RRK)	x	x	x	x					x	x	x			x						x			41%
Other Devices	Enhanced Company Operation (ECO) (**unfunded)		x		x							x		x	x	x		x						32%
	General Purpose Laptop		x		x							x				x								18%
	TLDHS / SLATE																x							5%
	Joint Tactical COP Workstation (JTCW) / C2 Personal Computer (C2PC)		x		x							x		x	x	x	x							
	BATS / HIIDE																		x					
	Tactical Operations Center (TOC) Kit / JCB-P Command Post (CP) variant		x									x		x	x									
	Intelligence Workstation (IW)		x									x		x	x	x		x						27%

	Company COC Dismounted	SIPRNet Access	SIPR Email & Browsing Applications	NIPRNet Access	NIPR E-Mail & Browsing Applications	Data (Radio)	DISN Extension	Voice (Radio push-to-talk)	Voice (POTS)	Voice (SATCOM push-to-talk)	Voice (VOSIP)	Chat Application	Free Text Message (Radio)	BFSA Application	COP/CTP Application	General Purpose Office Applications	Fires Application & Overlay	Intel Applications	Force Protection Application	VHF	SATCOM	HF	UHF	% of Requirements Mapped
Manpack Systems	PRC-117G	x		x		x		x		x			x							x	x		x	41%
	PRC-117F (**not used at company level in 2016)	x		x		x		x		x			x							x	x		x	41%
	PRC-150					x		x					x							x		x		23%
	PRC-152A Wideband Tactical Handheld Radio (WB THHR)	x				x		x		x			x							x	x		x	36%
	PRC-153 Inter- / Intra-Squad Radio (ISR)							x												x			x	14%
	Joint Battle Command-Platform Handheld (JBC-P(H))											x		x	x		x							18%
Vehicle Mount Systems	MRC-145																							
	VRC-114 (V)L																							
	VRC-110																							
	VRC-112																							
	VRC-111 / 113																							
	Blue Force Tracker (BFT) / JBC-P vehicle variant											x		x	x		x							23%
	Networking-on-the-Move (NOTM) Point of Presence (POP)																							
	NOTM Staff Vehicle Kit (SVK)																							
Stationary Systems	Very Small Aperture Terminal (VSAT)																							
	Wireless Point-to-Point Link (WPPL)																							
	MRC-142C																							
	Transition Switch Module (TSM); Remote Subscriber Access Module (RSAM) and Deployable End Office Suite (DEOS)																							
	Data Distribution System-Modular (DDS-M); Local Area Network (LAN) Extension Module (LEM) and Wide Area Network (WAN) Services Module (WSM)																							
	Expeditionary Command and Control Suite (ECCS) Rapid Response Kit (RRK)																							
Other Devices	Enhanced Company Operation (ECO) (**unfunded)		x		x							x		x	x	x		x						32%
	General Purpose Laptop		x		x							x				x								18%
	TLDHS / SLATE																x							5%
	Joint Tactical COP Workstation (JTCW) / C2 Persona Computer (C2PC)		x		x							x		x	x	x	x							32%
	BATS / HIIDE																		x					5%
	Tactical Operations Center (TOC) Kit / JCB-P Command Post (CP) variant																							
	Intelligence Workstation (IW)		x									x		x	x	x		x						27%

	Platoon Command Post (CP) and OTM	SIPRNet Access	SIPR Email & Browsing Applications	NIPRNet Access	NIPR E-Mail & Browsing Applications	Data (Radio)	DISN Extension	Voice (Radio push-to-talk)	Voice (POTS)	Voice (SATCOM push-to-talk)	Voice (VOSIP)	Chat Application	Free Text Message (Radio)	BFSA Application	COP/CTP Application	General Purpose Office Applications	Fires Application & Overlay	Intel Applications	Force Protection Application	VHF	SATCOM	HF	UHF
Manpack Systems	PRC-117G	X		X		X		X		X			X							X	X		X
	PRC-117F (**not used at company level in 2016)	X		X		X		X		X			X							X	X		X
	PRC-150					X		X					X							X		X	
	PRC-152A Wideband Tactical Handheld Radio (WBTHHR)	X				X		X		X			X							X	X		X
	PRC-153 Inter- / Intra-Squad Radio (ISR)							X												X			X
	Joint Battle Command-Platform Handheld (JBC-P(H))											X		X	X		X						
Vehicle Mount Systems	MRC-145	X		X		X		X												X			
	VRC-114 (V)1	X		X		X		X		X			X							X	X		X
	VRC-110	X		X		X		X		X			X							X	X		X
	VRC-112	X		X		X		X		X			X							X	X		X
	VRC-111 / 113							X		X										X			X
	Blue Force Tracker (BFT) / JBC-P vehicle variant											X		X	X		X						
	Networking-on-the-Move (NOTM) Point of Presence (POP)	X		X		X		X	X	X	X		X										
	NOTM Staff Vehicle Kit (SVK)		X		X							X		X	X		X				X		
Stationary Systems	Very Small Aperture Terminal (VSAT)	X		X			X				X										X		
	Wireless Point-to-Point Link (WPPL)	X		X			X		X		X										X		
	MRC-142C	X		X			X		X		X												
	Transition Switch Module (TSM); Remote Subscriber Access Module (RSAM) and Deployable End Office Suite (DEOS)								X		X												
	Data Distribution System-Modular (DDS-M); Local Area Network (LAN) Extension Module (LEM) and Wide Area Network (WAN) Services Module (WSM)	X		X																			
	Expeditionary Command and Control Suite (ECCS) Rapid Response Kit (RRK)	X	X	X	X					X	X	X			X								
Other Devices	Enhanced Company Operation (ECO) (**unfunded)		X		X							X		X	X	X		X					
	General Purpose Laptop		X		X							X				X							
	TLDHS / SLATE																X						
	Joint Tactical COP Workstation (JTCW) / C2 Personal Computer (C2PC)		X		X							X		X	X	X	X						
	BATS / HIIDE																		X				
	Tactical Operations Center (TOC) Kit / JCB-P Command Post (CP) variant		X									X		X	X								
	Intelligence Workstation (IW)		X									X		X	X	X		X					

	Squad Leader	SIPRNet Access	SIPR Email & Browsing Applications	NIPRNet Access	NIPR E-Mail & Browsing Applications	Data (Radio)	DSN Extension	Voice (Radio push-to-talk)	Voice (POTS)	Voice (SATCOM push-to-talk)	Voice (VOSIP)	Chat Application	Free Text Message (Radio)	BFSA Application	COP/CTP Application	General Purpose Office Applications	Fires Application & Overlay	Intel Applications	Force Protection Application	VHF	SATCOM	HF	UHF
Manpack Systems	PRC-117G																						
	PRC-117F (**not used at company level in 2016)																						
	PRC-150																						
	PRC-152A Wideband Tactical Handheld Radio (WB THHR)	x				x		x		x			x							x	x		x
	PRC-153 Inter- / Intra-Squad Radio (ISR)							x												x			x
	Joint Battle Command-Platform Handheld (JBC-P(H))											x		x	x		x						
Vehicle Mount Systems	MRC-145																						
	VRC-114 (V)1																						
	VRC-110																						
	VRC-112																						
	VRC-111 / 113																						
	Blue Force Tracker (BFT) / JBC-P vehicle variant																						
	Networking-on-the-Move (NOTM) Point of Presence (POP)																						
	NOTM Staff Vehicle Kit (SVK)																						
Stationary Systems	Very Small Aperture Terminal (VSAT)																						
	Wireless Point-to-Point Link (WPPL)																						
	MRC-142C																						
	Transition Switch Module (TSM); Remote Subscriber Access Module (RSAM) and Deployable End Office Suite (DEOS)																						
	Data Distribution System-Modular (DDS-M); Local Area Network (LAN) Extension Module (LEM) and Wide Area Network (WAN) Services Module (WSM)																						
	Expeditionary Command and Control Suite (ECCS) Rapid Response Kit (RRK)																						
Other Devices	Enhanced Company Operation (ECO) (**unfunded)		x		x							x		x	x	x		x					
	General Purpose Laptop		x		x							x				x							
	TLDHS / SLATE																						
	Joint Tactical COP Workstation (JTCW) / C2 Personal Computer (C2PC)																						
	BATS / HIIDE																						
	Tactical Operations Center (TOC) Kit / JCB-P Command Post (CP) variant																						
	Intelligence Workstation (IW)																						

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APPENDIX J. SYSTEM BASELINE AND ALLOCATION

System Baseline and Allocation Structure from COE for ICB-C2 (Combat Development and Integration, 2012)

<table>
<tr><th></th><th>System</th><th>Squad</th><th>Platoon</th><th>Company</th><th>General Notes</th></tr>
<tr><td rowspan="8">Manpack</td><td>PRC-150</td><td>-</td><td>1</td><td>1</td><td rowspan="8">The systems at the left are Manpack or handheld form factor, which are the primary systems used for Dismounted operations. Several of these Manpack systems may also be used at-the-halt or Fixed, such as within a patrol base or at the CLIC/CLOC. The PRC-152A and PRC-117G are the primary data radios, while others such as the PRC-150 have a limited data capability. The JBC-P(H) is highly dependent on accessibility to the PRC-152A and PRC-117G. The Marine Corps expects to field the most recent versions of tactical radios by 2016. In the event that there are limited quantities of PRC-152As, the legacy PRC-152s may be used in place as needed and available from the parent unit.</td></tr>
<tr><td>PRC-152</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>PRC-152A (ANW2)</td><td>2</td><td>2</td><td>4</td></tr>
<tr><td>PRC-148</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>JBC-P (H)</td><td>1</td><td>2</td><td>4</td></tr>
<tr><td>PRC-117F</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>PRC-117G</td><td>-</td><td>1</td><td>1</td></tr>
<tr><td>PRC-153 (IISR)</td><td>4</td><td>2</td><td>-</td></tr>
</table>

<table>
<tr><th></th><th>System</th><th>Squad</th><th>Platoon</th><th>Company</th><th>General Notes</th></tr>
<tr><td rowspan="9">Vehicle</td><td>VRC-104</td><td>-</td><td>-</td><td>0/1</td><td rowspan="9">The VRC systems at the left are the vehicle-mounted form factors of the Manpack PRC radios above, excluding the PRC-153 IISR. The notes for each system describe the specific relationships. The NOTM PoP and MRC-145 may be co-integrated into a single vehicle, while the NOTM SVK and C2 systems will be integrated into surrounding tactical vehicles used by the Company and subordinate units as needed. Similar to Manpack systems, these Vehicle systems may be used for Fixed operations depending on the mission requirements and constraints.</td></tr>
<tr><td>VRC-110</td><td>-</td><td>-</td><td>1</td></tr>
<tr><td>VRC-112</td><td>-</td><td>-</td><td>1</td></tr>
<tr><td>VRC-114 (V)1</td><td>-</td><td>-</td><td>1</td></tr>
<tr><td>VRC-111/113</td><td>-</td><td>-</td><td>0/4</td></tr>
<tr><td>MRC-145</td><td>-</td><td>-</td><td>0/1</td></tr>
<tr><td>NOTM PoP</td><td>-</td><td>-</td><td>0/1</td></tr>
<tr><td>NOTM/COC SVK</td><td></td><td></td><td>0/4</td></tr>
<tr><td>BFT / JBC-P Vehicle</td><td>-</td><td>-</td><td>Select vehicles</td></tr>
</table>

	System	Squad	Platoon	Company	General Notes
Stationary	JTCW/C2PC	-	-	**As needed**	The systems at the left will be used in fixed COCs to support permanent or semi-permanent operations. Many of these systems are being used more frequently at the company level, but they are not considered company assets. When e-mail, DISN, or VOIP services are need in order to maintain communications with the battalion and provide network access to several concurrent users, the company will employ either the VSAT, WPPL, or MRC-142C, but it will not need all three systems simultaneously. The quantities of JTCW/C2PC and ECO systems at the company level and below will depend on the mission need. The company will need more end-user devices when it is widely dispersed and must support full CLOC operations for extended periods of time. IMOs, communications planners and commanders at the battalion and company level must carefully evaluate mission requirements to understand the expected number of users, distances, threat risk, attachments, etc., and from that analysis select the optimal number of devices. This will consider the logistics and manpower burdens potentially placed on the company.
	JBC-P CP / TOC Kit	-	-	**1**	
	ECCS RRK	-	-	**0/1**	
	VSAT	-	-	**0/1**	
	WPPL	-	-	**0/1**	
	MRC-142C	-	-	**0/1**	
	TSM (RSAM, DEOS)	-	-	**0/1**	
	DDS-M (LEM or WSM)	-	-	**1**	
	IW	-	-	**0/1**	
	ECO Kits	**As needed**	**As needed**	**As needed**	

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APPENDIX K. CLOUD SERVICE MODELS

NIST Defined Service Models (from Mell & Grance, 2011, p. 2)

- Software-as-a-Service (SaaS). End users access service provider applications that are hosted on a cloud infrastructure typically via a web browser interface. The end users do not manage the underlying cloud infrastructure or individual application capabilities; however, limited local application configuration management permissions can be granted to select users.
- Platform-as-a-Service (PaaS). End users have the capability to host locally user-created or acquired applications on a cloud infrastructure so long as they were created using standards supported by the service provider. End users do not manage the underlying cloud infrastructure; however, they do have control over the hosted applications.
- Infrastructure-as-a-Service (IaaS). End users devices use the cloud infrastructure to access and manage end user applications. End users do not manage the underlying cloud infrastructure; however, they do have control over the applications, operating systems, and storage provisioned.

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APPENDIX L. USMC FUTURE VISION OF C2

USMC MAGTF C2 Characteristics of Future Communication Systems (Marine Corps Combat Development Command, 2013, p. 24)

- Common: Command echelons use the same equipment. Unique MAGTF sensors and intelligence feeds enter via a standard gateway.
- Modular: C2 systems are designed to enable component utilization that logically supports a variety of configurations for various C2 echelons.
- Scalable: Software and hardware components are added and subtracted to facilitate C2 functions for all sizes of MAGTF operations centers.
- Interoperable: C2 using SoS must possess the interoperability necessary to ensure success in joint and multinational operations as well as interactions with Other Government Agencies (OGAs) and Non-Governmental Organization (NGOs).
- Trusted: C2 system users must have confidence in the capabilities of the network and the validity of the information made available by the network.
- Shared: Sharing allows for the mutual use of the information services or capabilities between entities of the operational environment. This ability may cross functional or organizational boundaries. In addition, organizational entities need to adopt the shared meta-metadata model. Squads need the ability to communicate directly with the platoon and company but also have direct liaison authority to radio battalion in order to plan based off of all available collaborative shared and fused information. Also, this may require data flow from higher-to-lower security classifications in order to incorporate ISR into C2. Proper policies are critical to incentivize the data sharing between SoS.
- Agile: To support expeditionary forces and operational concepts, the communications system must be agile. The key dimensions of C2 and communications system agility are:
- Responsiveness: The ability to react to a change in the environment in a timely manner.
- Flexibility: The ability to employ multiple methods to succeed and the capacity to move seamlessly between them.
- Innovation: The ability to do new things and the ability to do old things in new ways.
- Adaptation: Intelligent semi-automatic capability that can capture dynamically changing knowledge to be able to change work flows

- Reliability: Available when needed and perform as intended with low failure rates and few errors.
- Customization of data views: The ability to adjust to suit the needs of the end user. Seamless ability to switch from one form (networked graph) to another (METOC gridded data) or picture in picture. Drill-down from an aggregate-to-lower level where the detailed or raw information is at the leaf level.

LIST OF REFERENCES

Alberts, D. S., & Hayes, R. E. (2003). *Power to the edge: Command...control...in the information age.* Washington, DC: Office of the Assistant Secretary of Defense Washington, DC Command and Control Research Program. Retrieved from: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA457861

Assistant Secretary of Defense. (2001). Department of Defense policy on procurement of mobile satellite services. Washington, DC: Secretary of Defense: Retrieved from: https://inah.pac.disa.mil/fouo/files/ASDpolicy.pdf

Acquisition Community Connection. (2015). Spectrum tools. Retrieved from: https://acc.dau.mil/CommunityBrowser.aspx?id=346146

Chairman of the Joint Chiefs of Staff. (2011). *The national military strategy of the United States of America 2011*. Washington, DC: Department of Defense. Retrieved from: https://acc.dau.mil/adl/en-U.S./425505/file/55897/2011%20National%20Military%20Strategy.pdf

Coakley, T. P. (1992). *Command and control for war and peace.* Washington, DC: DIANE Publishing.

Combat Development and Integration (CD&I). (2012). Concept of employment for an infantry company and below command and control (ICB-C2). Washington, DC: Headquarters Marine Corps.

Conway, J. T. (2008). *Marine Corps vision and strategy 2025.* Retrieved from: http://www.onr.navy.mil/~/media/Files/About-ONR/usmc_vision_strategy_2025_0809.ashx

Datawarehouse4u.info. (2010). OLTP vs. OLAP. Retrieved from: http://datawarehouse4u.info/OLTP-vs-OLAP.html

Defense Business Board. (2013). Taking advantage of opportunities for commercial satellite communications services. [PowerPoint Presentation]. Retrieved from: http://www.defensedaily.com/Assets/DBB_SATCOM.pdf

Defense Information Systems Agency. (2014a). Multinational information sharing. Retrieved from: http://www.disa.mil/Mission-Support/Command-and-Control/MNIS

Defense Information Systems Agency. (2014b). Secret IP data. Retrieved from: http://www.disa.mil/Network-Services/Data/Secret-IP

Defense Information Systems Agency. (2014c). Sensitive but unclassified IP data. Retrieved from: http://www.disa.mil/Network-Services/Data/Secret-IP

Department of the Army. (1993). *Infantry division operations tactics, techniques, and procedures* (FM 71–100–2). Washington, DC: Headquarters Department of the Army. Retrieved from: http://www.patriotresistance.com/FM-71–100–2-Infantry-Division-Operations-and-Tatics-August1993.pdf

Department of the Army. (2000). *Medical evacuation in theater operations* (FM 8–10–06). Washington, DC: Headquarters Department of the Army. Retrieved from: http://www.globalsecurity.org/military/library/policy/army/fm/8–10–6/fm8–10–6-2000.pdf

Department of the Army. (2006). *Human intelligence collector operations* (FM 2–22.3). Washington, DC: Headquarters Department of the Army. Retrieved from: http://armypubs.army.mil/doctrine/DR_pubs/dr_a/pdf/fm2_22x3.pdf

Deputy Commandant for Combat Development and Integration. (2010). *Marine Corps operating concepts: Third edition*. Washington, DC: Headquarters Marine Corps. Retrieved from: http://www.hqmc.marines.mil/Portals/142/Docs/MOC%20July%2013%20update%202010_Final%5B1%5D.pdf

Dillingham, R.F., & Nathans, D. (2007). *CrossTalk: The Journal of Defense Software Engineering*, 20(7) 22–23. Retrieved from: http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA487095

Director for Command, Control, Communications, and Computers (C4) and the Department of the Navy Deputy Chief Information Officer, (2013, April). *Marine Corps commercial mobile device strategy*. Washington, DC: Author. Retrieved from: http://www.hqmc.marines.mil/Portals/156/Newsfeeds/SV%20Documents/20130411_Marine_Corps_Commercial_mobile_device_strategy_Final.pdf

Holm, R. (2006). Why convert to a SAASM-based global positioning system. *Military Embedded Systems*. Retrieved from: http://mil-embedded.com/pdfs/Symmetricom1.Oct05.pdf

J-FIRE. (1997). Multiservice procedures for the joint application of firepower. Retrieved June 15, 2015, from: http://www.globalsecurity.org/wmd/library/policy/dod/t0302060.pdf

Joint Chiefs of Staff. (2012). *Capstone concept for joint operations: Joint force 2020*. Washington, DC: Department of Defense. Retrieved from: http://www.defenseinnovationmarketplace.mil/resources/JV2020_Capstone.pdf

Jones, K., Jenkins, L., & Ramsey, J. (2005). Holistic systems engineering: Physical, informational, and cognitive domains. *Digital Avionics Systems Conference, 2005. DASC 2005. the 24th*, vol. 2. pp. 11. Retrieved from: http://ieeexplore.ieee.org.libproxy.nps.edu/stamp/stamp.jsp?tp=&arnumber=1563483

Krulak, C. C. (1999). The strategic corporal: Leadership in the three block war. *Marines Magazine,* January 1999. Retrieved from: http://www.au.af.mil/au/awc/awcgate/usmc/strategic_corporal.htm

Kundra, V. (2011). Federal cloud computing strategy. Retrieved from: http://www.mail.governmenttrainingcourses.net/pdfs/Federal-Cloud-Computing-Strategy1.pdf

Liguori, M., & Daniel, N. (2013). Secure mobile cellular capabilities: Value analysis for expeditionary combat units. (Master's thesis). Naval Postgraduate School, Monterey CA.

Marine Corps Combat Development Command. (2007). *MAGTF command and control concept of operations*. Arlington, VA: Headquarters Marine Corps.

Marine Corps Combat Development Command. (2008). *Combat operations center (COC) study capability set (CAPSET) V for Marine Corps air-ground task force (MAGTF) command and control (C2)*. Arlington, VA: Headquarters Marine Corps.

Marine Corps Combat Development Command. (2013). *MAGTF C2 roadmap*. Arlington, VA: Headquarters Marine Corps.

Marine Corps Concepts and Programs. (2015a). Advanced field artillery tactical data system (AFATDS) Family of Systems (FoS). Retrieved June 15, 2015, from: https://marinecorpsconceptsandprograms.com/programs/fire-support/advanced-field-artillery-tactical-data-system-afatds-family-systems-fos

Marine Corps Concepts and Programs. (2015b). Distributed common ground-surface system Marine Corps (DCGS-MC). Retrieved June 15, 2015, from: https://marinecorpsconceptsandprograms.com/programs/intelligence-surveillance-and-reconnaissance/distributed-common-ground-surface-system

Marine Corps Systems Command, (n.d.a). Advanced field artillery tactical data system (AFATDS) [Fact sheet]. Retrieved June 15, 2015, from: http://www.marcorsyscom.marines.mil/Portals/105/PMMC3/MC3PDF/DFSA%20AFATDS%20FACT%20SHEET.pdf

Marine Corps Systems Command. (n.d.b). Joint battle command-platform family of systems (JBC-P FoS). [Fact sheet]. Retrieved June 15, 2015 from: http://www.marcorsyscom.marines.mil/Portals/105/PMMC3/MC3PDF/DFSA%20JBC-P%20FoS%20FACT%20SHEET.pdf

Mell, P., & Grance, T. (2011). The NIST definition of cloud computing. Retrieved from: http://csrc.nist.gov/publications/nistpubs/800–145/SP800–145.pdf

Military Wireless Communications (MWC). (n.d.) Retrieved from the Naval Postgraduate School Cebrowski Institute: http://faculty.nps.edu/cdprince/mwc/mwc.html

Monica, O. (2012, August 20). Task 13: OLAP vs OLTP | A day in the life of a BI developer [Blog post]. Retrieved from: http://businessintelligencedev.blogspot.com/2012/08/task-13-olap-vs-oltp.html

National Academics Press (NAP). (2006). C4ISR for future naval strike groups. Retrieved from: http://www.nap.edu/openbook.php?record_id=11605&page=1

Naval Research Advisory Committee. (2012). *Lightening the information load*. (Naval Research Advisory Committee Report). Washington, DC: Office of the Secretary of the Navy. Retrieved from: http://www.nrac.navy.mil/docs/NRAC_2012_Final_Report-Lightening_the_load_15Feb13.pdf

Nesamoney, D., Chandra, P. S., Gupta, S., Pancha, G., Taylor, J. B., & Zamanian, M. K. (2000). *U.S. patent no. 6,044,374*. Washington, DC: U.S. Patent and Trademark Office. Retrieved from: http://www.google.com/patents/US6044374

Office of the Department of Defense Chief Information Officer. (2006). *Department of Defense enterprise architecture federation strategy*. Washington, DC: Department of Defense. Retrieved from: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&sqi=2&ved=0CB4QFjAAahUKEwjJzeiSkoLHAhUElYgKHS1KCxk&url=http%3A%2F%2Fwww.eng.auburn.edu%2Fcse%2Fclasses%2Fcomp7700%2Fresources%2FGIG_Architecture.doc&ei=r7i5VYm6N4SqogStlK3IAQ&usg=AFQjCNFDi8sl8Zw-za5gfxb33phBpKXuNQ&sig2=L21fSxiSTZ8d466ioSHGGw&bvm=bv.99028883,d.cGU

Office of the Department of Defense Chief Information Officer. (2012a). *Cloud computing strategy*. Washington, DC: Department of Defense. Retrieved from: http://www.disa.mil/Services/~/media/Files/DISA/Services/Cloud-Broker/DOD-cloud-strategy.pdf

Office of the Department of Defense Chief Information Officer. (2012b). *Department of Defense mobile device strategy* (version 2.0). Washington, DC: Department of Defense. Retrieved from: http://www.defense.gov/news/DODmobilitystrategy.pdf

Oregon, R. S. (2011). S*mart fires: A COTS approach to tactical fire support using a smartphone.* (Master's thesis). Retrieved from: http://hdl.handle.net/10945/5469

Powell Jr, D. A. (2013). *The military applications of cloud computing technologies*. Retrieved from: http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA589625

Power, D. J. (2008). Decision support systems: a historical overview. In *Handbook on Decision Support Systems 1*. Retrieved from: http://download.springer.com/static/pdf/178/bok%253A978-3-540-48713-5.pdf?originUrl=http%3A%2F%2Flink.springer.com%2Fbook%2F10.1007%2F978-3-540-48713-5&token2=exp=1438239659~acl=%2Fstatic%2Fpdf%2F178%2Fbok%25253A978-3-540-48713-5.pdf%3ForiginUrl%3Dhttp%253A%252F%252Flink.springer.com%252Fbook%252F10.1007%252F978-3-540-48713-5*~hmac=236fc3a9cba52f8ae6859810832ce4cf868ceac86433745acb225b331edba593

PHOTOINDEX.W.PW. (2008). CAS 9-line card. Retrieved from: http://photoindex.w.pw/views/CAS_9_Line_Card/Sign_Into_your_Account/aW1nLmRvY3N0b2NjZG4uY29tL3RodW1iL29yaWcvNDY2MDg3NjkucG5n.php

Public Affairs Office of the New Jersey Department of Military and Veteran Affairs. (2009). *Guardlife. The Magazine of the New Jersey National Guard, 35*(5), 28. Retrieved from: http://www.state.nj.us/military/publications/guardlife/volume34no5/Guardlife%20V34N5.pdf

Pujari, A. K. (2001). *Data mining techniques*. Hyderabad, India: Universities Press.

Reddy, G. S., Srinivasu, R., Rao, M., & Rikkula, S. R. (2010). Data warehousing, data mining, OLAP and OLTP technologies are essential elements to support decision-making process in industries. *International Journal on Computer Science and Engineering*, *2*(9), 2865–2873. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.301.5615&rep=rep1&type=pdf

Reddy, P. (2012). PM MAGTF command, control, and communications (MC3) overview. [PowerPoint presentation]. Retrieved from: http://www.afcea-qp.org/wp-content/uploads/2012/12/MC3_AFCEA_OVERVIEW_NOV_2012_v3.pdf

RedWireDesigns. (n.d.). Call for fire card. Retrieved from: http://redwiredesigns.deviantart.com/art/Call-For-Fire-Card-126186679

Satyanarayanan, M., Bahl, P., Caceres, R., & Davies, N. (2009). The case for VM-based cloudlets in mobile computing. *Pervasive Computing, IEEE, 8*(4), 14–23. Retrieved from: http://elijah.cs.cmu.edu/DOCS/satya-ieeepvc-cloudlets-2009.pdf

Satyanarayanan, M., Lewis, G., Morris, E., Simanta, S., Boleng, J., & Ha, K. (2013). The role of cloudlets in hostile environments. *Pervasive Computing, IEEE, 12*(4), 40–49. Retrieved from: http://elijah.cs.cmu.edu/DOCS/satya2013-hostile-environments.pdf

Strassman, P. (2011). Two barriers block new architecture. *Signal Magazine Online*. Retrieved from: http://www.afcea.org/content/?q=node/2786

Taft, D. K. (2015). One-third of BI pros spend up to 90% of time cleaning data [Electronic newsletter]. Retrieved from: http://www.eweek.com/database/one-third-of-bi-pros-spend-up-to-90-of-time-cleaning-data.html

Takai, T. (2012). Achieving DOD IT effectiveness [PowerPoint presentation]. Washington, DC: Department of Defense. Retrieved from: https://acc.dau.mil/adl/en-US/496844/file/62657/Achieving%20DoD%20IT%20Effectiveness.pdf

Truong, H., & Dustdar, S. (2009). On analyzing and specifying concerns for data as a service. *Services Computing Conference, 2009. APSCC 2009. IEEE Asia-Pacific,* 87–94. Retrieved from: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5394136&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D5394136

Truong, H., & Dustdar, S. (2010). On evaluating and publishing data concerns for data as a service. *Services Computing Conference (APSCC), 2010 IEEE Asia-Pacific,* 363–370. Retrieved from: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5708592

U.S. Marine Corps. (1996). *Command and control* (MCDP-6). Washington, DC: Headquarters Marine Corps. Retrieved from: https://fas.org/irp/DODdir/usmc/mcdp6.pdf

U.S. Marine Corps. (1998). *Organization of Marine Corps forces* (MCRP 5–12D). Washington, DC: Headquarters Marine Corps. Retrieved from: http://www.marines.mil/Portals/59/Publications/MCRP%205–12D%20Organization%20of%20Marine%20Corps%20Forces.pdf

U.S. Marine Corps, (2004). *Assault support* (MCWP 3–24). Washington, DC: Author. Retrieved from: http://www.marines.mil/Portals/59/Publications/MCWP%203–24%20Assault%20Support.pdf

U.S. Marine Corps. (2010a). *Marine Corps warfighting publication 3–40.3*. Washington, DC: Author. Retrieved from: https://www.doctrine.usmc.mil/restrictedpubs/w3403.pdf

U.S. Marine Corps. (2010b). *USMC concepts and programs 2010*. Washington, DC: Retrieved from: http://www.hqmc.marines.mil/Portals/136/Docs/Concepts%20and%20Programs/2010/Ch%2003_b.pdf

U.S. Marine Corps. (2011a). *Marine Corps operations* (MCDP 1–0). Washington, DC: Author. Retrieved from: https://www.doctrine.usmc.mil/signpubs/d10.pdf

U.S. Marine Corps. (2011b). *Marine Corps supplement to the Department of Defense dictionary of military and associated terms* (MCRP 5–12C). Washington, DC: Headquarters Marine Corps. Retrieved from: http://www.marines.mil/Portals/59/Publications/MCRP%205–12C%20Marine%20Corps%20Supplement%20to%20the%20DOD%20Dictionary%20of%20Military%20and%20Associated%20terms.pdf

U.S. Marine Corps. (2012). *Marine Corps bulletin 4081 (MCBUL 4081)*. Washington, DC: Retrieved from: http://www.marines.mil/Portals/59/Publications/MCBUL_%204081%20DTD%2022MAY12.pdf

U.S. Marine Corps. (2014a). *Infantry company operations (MCWP 3-11.1)*. Washington, DC: Author. Retrieved from: http://www.trngcmd.marines.mil/Portals/207/Docs/TBS/MCWP%203-11.1%20Infantry%20Company%20Operations.pdf

U.S. Marine Corps. (2014b). *Marine Corps task list 2.0 (MCTL) Section 5* (Marine Corps Order 3500.26_). Washington, DC: Retrieved from: http://www.mccdc.marines.mil/Portals/172/Docs/MCTL/MCTL%201%20DEC%202014.docx

U.S. Marine Corps. (2014c). *Total force structure management system (TFSMS): Unit TO&E report*. Washington, DC: Author. Retrieved from: https://tfsms-cognos.mccdc.usmc.mil/crn/cgi-bin/cognosisapi.dll?b_action=cognosViewer&ui.action=run&ui.object=%2fcontent%2ffolder%5b%40name%3d%27Standard%20Reports%20(Published%2c%20structure%20data%20current%20as%20of%20last%20ASR)%27%5d%2freport%5b%40name%3d%27Unit%20TO%26E%20Report%27%5d&ui.name=Unit%20TO%26E%20Report&run.outputFormat=&run.prompt=false&p_UIC=M11163&p_FY=2015&run.outputFormat=PDF#

U.S. Navy. (2012). *Navy supplement to the Department of Defense dictionary of military and associated term*. (NTRP 1–02). Washington, DC: Office of the Chief of Naval Operations. Retrieved from: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA562336

U.S. Strategic Command. (2013). *Fiscal year 2011 commercial satellite communications usage report in response to the Chairman of the Joint Chiefs of Staff instruction 6250.1E.*

Van Creveld, M. L. (1985). *Command in war*. Cambridge, MA: Harvard University Press.

Vu, Q. H., Pham, T., Truong, H., Dustdar, S., & Asal, R. (2012). Demods: A description model for data-as-a-service. *Advanced Information Networking and Applications (AINA), 2012 IEEE 26th International Conference on,* 605–612. Retrieved from: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6184925&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D6184925

Wang, J. (2008). *Data warehousing and mining: Concepts, methodologies, tools, and applications*. Hershey: IGI Global.

Weippl, E., Mangisengi, O., Essmayr, W., Lichtenberger, F., & Winiwarter, W. (2001, October). An authorization model for data warehouses and OLAP. In *Workshop on Security in Distributed Data Warehousing," New Orleans*. Retrieved from: http://www.researchgate.net/profile/Oscar_Mangisengi/publication/2519115_An_Authorization_Model_for_Data_Warehouses_and_OLAP/links/00b4952b4d23b5a7bf000000.pdf

Welsh, W. (2012). Network validation effort sets stage for Army's upcoming NIE 13.1. *Defense Systems*. Retrieved from: http://defensesystems.com/articles/2012/10/04/army-validation-exercise-nie.aspx?admgarea=DS

Yang, K. (2011). An adaptive communication solution applying COTS cellular technology to technical communications. (Master's thesis). Retrieved from: http://calhoun.nps.edu/public/bitstream/handle/10945/5524/11Sept_Yang.pdf?sequence=1

Young, L., & Ishii, M. (2012). One force tactical communications system: Connecting the tactical edge at AEWE spiral G. *Military Communications Conference, 2012–Milcom 2012,* 1–4. doi:10.1109/MILCOM.2012.6415773. Retrieved from: http://ieeexplore.ieee.org.libproxy.nps.edu/stamp/stamp.jsp?tp=&arnumber=6415773

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